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Verification Of FAA's Emissions And Dispersion Modeling System (EDMS)

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VERIFICATION OF FAA'S EMISSIONS AND DISPERSION MODELING SYSTEM (EDMS)

by

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ABSTRACT

Air quality has been a major environmental concern for many years. Recently the issue of airport emissions has presented growing concerns and is being studied in much more depth. Airport emissions come from a variety of point, line and area sources, making emissions modeling for airports very complex and more involved. Accurate air quality models, specific to airport needs, are required to properly analyze this complex array of air pollution sources created by airports. Accurate air quality models are needed to plan for increased growth of current airports and address concerns over proposed new ones.

The Federal Aviation Administration's (FAA) Emissions and Dispersion Modeling System (EDMS) is a program that is the required model for assessing emissions from airport sources. This research used EDMS Version 4.21, which incorporates the EPA dispersion model AERMOD, to model detailed airport data and compare the model's predicted values to the actual measured carbon monoxide concentrations at 25 locations at a major U.S. airport. Statistics relating the model characteristics as well as trends are presented. In this way, a thorough investigation of the accuracy of the EDMS modeled values of carbon monoxide was possible. EDMS modeling included two scenarios, the first scenario referred to as practice detail included general airport information that a modeler could find from the airport being studied and the second scenario referred to as research detail utilized very detailed information from observer logs during a three day observation period. Each of the modeling scenarios was compared to the field measured data and to each other. These comparisons are important to insure the model is adequately describing emissions sources at airports. Data analysis of this study was

disappointing since measured levels of CO were generally higher than modeled values. Since EDMS is continually changing and improving perhaps these results can help enhance future models.

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Lastly, I need to express my gratitude to my mother and my fiancé, Nate Boyd, who have continued to love me and encourage me in good times as well as bad.

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CHAPTER 1 – INTRODUCTION

Air quality has received much attention over the last few decades and has become a major environmental concern as reported in 2000 by the General Accounting Office, which cited airport air quality as the second most important environmental concern effecting United States citizens (U.S. General Accounting Office 2000).   This concern has brought air quality at airports under review. Airports are both indirect sources of pollution and may have direct sources on the property as well. While not being a source in itself, they are a hub for aircraft, buses, cars, furnaces, boilers, training fires, etc. Airport properties are a complex mixture of point sources, line sources, and volume sources. This complex array of pollution sources can present quite a challenge when investigating air quality at these locations. Accurate air quality models, specific to airport needs are required to properly analyze air pollution in and around airports. Accurate models would also help to plan for increased growth and development in airports as well as to develop appropriate policies and procedures to address air quality concerns at these locations.

The required computer tool for assessing emissions at airports is the Federal Aviation Administration's office of Environment and Energy (FAA/AEE's) Emissions and Dispersion Modeling System (EDMS). This model has been the FAA required model for aviation sources since 198l, but has not undergone a systematic verification since the dispersion algorithms have been continually updated and changed. The FAA's Office of Environment and Energy, with support from the Environmental Measurement and Modeling Division at the United States Department of Transportation's John A. Volpe National Transportation Systems Center (Volpe Center) is engaged in a multi-year verification effort of FAA/AEE's Emissions and Dispersion

Modeling System (EDMS). The latest version of EDMS uses the EPA's dispersion model AERMOD, which has been validated primarily for point sources. Sources at airports include line, area and volume sources therefore this study is very important to insure the model is adequately describing all the different sources at airports. All EPA guidance for dispersion methodologies and characterization of emission sources are followed in the EDMS methodology. The EDMS modeled output values were compared with real measured data to determine the accuracy of the program's modeling capabilities for airports.

Many pollutants are of concern in air quality. The National Ambient Air Quality Standards (NAAQS) identifies primary pollutants as well as secondary pollutants, and their maximum concentrations associated with specific averaging times. Primary pollutants are emitted directly from the source, whereas secondary pollutants are formed from reactions in the atmosphere. The major pollutants of concern at airports include: ozone, VOCs, NO_x, particulate matter, SO_2, CO, and lead. EDMS has the capabilities of modeling eight different pollutants including: CO, THC, NMHC, VOC, NO_x, SO_x, PM-10, and PM-2.5. Carbon monoxide, (CO) is a primary pollutant that is a major concern at airports and can be modeled in EDMS. Historically CO concentration has been used as an overall air quality indicator in studies (Kenney 1992). Carbon monoxide is relatively stable in the atmosphere with a life span of approximately 4 months in the mid-latitudes (Seinfeld and Pandis 1998). The choice of CO as the comparative gas reduces physical complications, such as chemical reactions and allowed the focus of this study to be on the dispersion characteristics of the model.

The study discussed in this research included the measurement of carbon monoxide concentrations at 25 locations in the vicinity of Dulles International Airport (IAD), as well as a detailed accounting of all related aircraft activity, both airside and landside, and detailed weather data during the course of the CO measurements. This data was used as EDMS inputs and was the basis for the analysis presented in this thesis. The carbon monoxide measurements were collected using a bag collection technique. Six specific hours were chosen to capture the mid-morning peak, the afternoon peak as well as the maximum evening peak (Kenney 1992). The mid-morning peak was assumed to occur from 8am to 10am. This time period would also capture employees arriving to work. The afternoon peak was assumed to occur from noon to 2pm. This time period would also capture employees leaving and returning from lunch breaks. The evening time period used was from 4pm to 6pm. The study by Kenney showed the evening peak for carbon monoxide at several large airports occurred from 4pm to 10m, but due to the ability of the equipment and personnel in this study maximum sampling periods of two hours were used.

In addition to CO concentrations, other data included aircraft types, taxiways, runways, ground support equipment activity, auxiliary power unit activity, roadway and parking lot activities, as well as meteorological data. This data was used to create the actual scenarios as detailed files in EDMS for the same time periods the carbon monoxide measurements took place and provided the basis for the analysis presented in this thesis. There are multiple ways to assess the prediction value of a model, but the most common is a plot of measured versus modeled values. A perfect agreement between the model's predicted values and field measured values is a 45-degree line, above the line corresponds to over predicted values and below the line corresponds to under predicted values. Linear regression plots of modeled versus measured data are located in Appendix B. Figures 125-160 are graphs included for each sampling hour of the three day study. These are included as a visual reference of agreement between EDMS and the actual measured CO concentrations.

CHAPTER 2 – LITERATURE REVIEW

EDMS started as the Graphical Input Microcomputer Model (GIMM) in 1985 as a complex source model designed to assess the air quality impacts of proposed airport development projects. It became EDMS in 1991 as an enhanced model that was available for personal computers. EPA listed EDMS as a preferred guideline model for aviation sources in 1993. In response to the growing needs of air quality analysis and changes in the regulations (e.g., conformity requirements from the Clean Air Act Amendment of 1990), the FAA, in cooperation with the United States Air Force (USAF), re-engineered and enhanced EDMS in 1997 and released Version 3.0 (EPA 2000). The FAA revised its policy on air quality modeling procedures in 1998 to identify EDMS as the required model to perform air quality analyses for aviation sources to help ensure the consistency and quality of aviation analyses performed for the FAA. The FAA continues to enhance the model under the guidance of its government/industry advisory board to more effectively determine emission levels and concentrations generated by typical airport emission sources. The FAA completely reconfigured EDMS to take advantage of new data and algorithm developments, and in May 2001 released the software as EDMS version 4.0. EDMS 4.0 was developed under the guidance of a government/industry advisory board composed of experts from the scientific, environmental policy, and analysis fields. In October 2002, the FAA released EDMS version 4.1, which updated not only the ground support equipment (GSE) assignments, but updated their emission factors as well as including EPA's NONROAD model derived emission factors and bitmap views of the airport layout (FAA 2004).

The latest generation, EDMS 4.21, includes more pollutants as well as a greater accuracy and flexibility to model vehicle emissions, terrain, and meteorological data within the model. EDMS is designed to assess the air quality impacts of airport emission sources, particularly aviation sources, which consist of aircraft, auxiliary power units, and ground support equipment. EDMS also offers a limited capability to model other airport emission sources that are not aviation-specific but integral to the operation of any airport. These include ground access vehicles, training fires, fueling sources, and stationary sources. EDMS is one of the few air quality assessment tools specifically engineered for the aviation community and it includes both emission estimations and dispersion modeling capabilities. LASPORT is the European airport modeling program and contains databases specific to their aircraft and automobiles which are different than the US (Celiket et al. 2002). EDMS 4.21 which was used this study includes the latest aircraft engine emission factors from the International Civil Aviation Organization (ICAO) Engine Exhaust Emissions Data Bank (U.S. Environmental Protection Agency 1984) vehicle emission factors from the Environmental Protection Agency's (EPA) MOBILE6.2 (EPA 1994), and incorporates EPA's AERMOD dispersion model (EPA 1998). The model uses EPA's MOBILE 6.2 model, the latest version of AERMOD, and an interface to EPA's AERMAP and AERMET. MOBILE6.2 is EPA's recommended emission factor model for mobile sources, such as roadways and parking lots. AERMOD is EPA's preferred model for modeling air pollution dispersion. AERMAP is the terrain processor utilized in AERMOD, and the AERMET is its meteorological processor.

EDMS version 4.21 includes EPA's latest AERMOD dispersion algorithm, which has been validated for point source emissions (EPA 1995). AERMOD's utilization in EDMS is based on guidance from the American Meteorological Society/EPA Regulatory Model Improvement Committee (AERMIC), which is responsible for developing AERMOD and introducing state-of-the-art modeling concepts into the EPA's local-scale air quality models. AERMOD was suggested as a replacement for EPA's ISCST3 in late April of 2000. However before this substitution was able to take the place, many enhancements to the model were necessary including the addition of the building downwash algorithm from ISCST, PRIME. Some of these changes included modifications to the terrain and meteorological processor utilized in AERMOD. In Appendix W of 40 CFR Part 51 the EPA lists AERMOD as their recommended model (Code of Federal Regulations).

AERMOD's capabilities in air quality modeling convinced the FAA to incorporate it into their Emissions Dispersion Modeling System (Wayson 2001). It is important to understand some of the dispersion equations and methods used in AERMOD since it is the base model incorporated into EDMS. AERMOD utilizes two different methods for accounting for air dispersion depending on the section of the planetary boundary layer. The greater the elevation above the earth's surface the more stable the atmosphere becomes in the general sense. This creates complexities since the most common area of interest is closer to the earth's surface in the more turbulent atmosphere. In the convective planetary boundary layer (CBL, closer to the earth's surface), only the horizontal direction is considered to be Gaussian in its distribution, unlike the stable planetary boundary layer (SBL), where both the vertical and horizontal directions are treated as a Gaussian distribution. In a steady state condition, a continuous point source is modeled using the Gaussian approximation in Equation 1 (Cooper and Alley 2002). The atmospheric stability, or how well air mixes is accounted for in the determination of the standard deviation terms, σ_y and σ_z.

$$C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad [1]$$

Equation 1 Gaussian Approximation

where

C= point concentration a receptor, $\mu g/m^3$

H= effective height of emissions, in m

Q= mass flow of contaminants from receptor, $\mu g/s$

u= wind speed, in m/s

(x,y,z) = ground level coordinates of receptor, in m

σ_y= standard deviation of plume concentration distribution in the y plane, in m

σ_z= standard deviation of plume concentration distribution in the z plane, in m

In the convective boundary layer the vertical distribution is accounted for with a bi-Gaussian probability density function. This unstable condition even allows air to flow up into the stable layer and back down as well. Atmospheric stability is better accounted for in the Bi-Gaussian equation because it dictates how and to what extent the plume will move between the planetary boundary layers. This wavering path is more descriptive of the plume's actual path in unstable atmospheric conditions, and less wavering would occur in stable conditions. The general equation for concentration calculations in either of the boundary layers is Equation 2.

$$C_T\{x_r, y_r, z_r\} = f \bullet C_{c,s}\{x_r, y_r, z_r\} + (1-f)C_{c,s}\{x_r, y_r, z_p\} \qquad [2]$$

Equation 2 Bi-Gaussian Equation for Concentration for Stable or Convective Conditions

where

$C_T\{x_r,y_r,z_r\}$ = total concentration

f = the plume state weighting function

$C_{c,s}\{x_r,y_r,z_r\}$= concentration contribution from the terrain-following state

$C_{c,s}\{x_r,y_r,z_p\}$= concentration taking into account the receptor height above terrain level (z_p)

This Bi-Gaussian equation considers the total concentration to be the sum of two terms. The first term is the horizontal plume concentration in both the convective boundary (C_c) and the stable boundary (C_s) for the receptor designated with an x, y, and z coordinate. The first term is multiplied by the plume state weighting function, f, where f is defined by Equation 3.

$$f = 0.5(1+\varphi_p) \qquad [3]$$

Equation 3 Plume State Weighting Function

where

f= plume state weighting function

φ_p = streamline height

The second term in the general Bi-Gaussian equation includes the concentration from the terrain following plume for both boundary layers. It also includes the receptor location, accounting for the height of the receptor above terrain, z_p. This height correction is not necessary in flat terrain because z_r=z_p. This concentration term at the receptor location, multiplied by the remaining fraction of the plume weighting function makes up the second term in the general equation. (EPA 2004a).

The way in which the air moves in the environment is influenced by a number of natural phenomena such as the natural heating and cooling that occurs during a night and day cycle causing changes in the buoyancy of the air as its temperature changes. Terrain creates friction with the atmosphere causing the air to move over or to impact the obstruction. The streamline height, the height at which the air will rise over an obstacle, is zero for neutral and unstable conditions. The flow paths below this streamline height will not flow over the obstruction. This concept of streamline height (H_c or φ_p) is important in understanding the plume weighting function (Equation 2). The plume weighting function is actually a way of characterizing how much of the plume will be above and below the streamline height, i.e. how much of the plume will rise over the obstacle.

$$\varphi_p = \frac{\int_0^{H_C} C_s\{x_r, y_r, z_r\}dz}{\int_0^{\infty} C_s\{x_r, y_r, z_r\}dz} \qquad [4]$$

Equation 4 Fraction of Plume below Streamline Height

φ_p = streamline height

$C_s\{x_r,y_r,z_r\}$= concentration in the absence of terrain for stable conditions

The actual fraction of plume material is calculated using Equation 3 once the streamline height is determined. Recall that the streamline height will be zero in convective conditions (neutral and unstable), causing the top term in Equation 4 to go to 0, thus resulting in a φ_p equal to 0 and yielding a plume weight factor (f) of 0.5. The same result of an equal weight factor, f=0.5, occurs when the entire plume is above the streamline height. This is to account for horizontal spreading that will occur around an obstacle even as much of the plume mass rises over it (Figure 1). This horizontal spreading that is always occurring is in response to the stability of the atmosphere more than the effects of the terrain at this point. However, when the entire plume is below the streamline height, the concentration from the stable boundary is zero thus producing a φ_p equal to 1. This yields a plume weighting factor of 1, causing the terrain following term to go to zero. As a result, when the plume resides completely in the convective layer, the concentration calculation in the general equation is calculated from the first term only, the horizontal plume concentration (EPA 2004a).

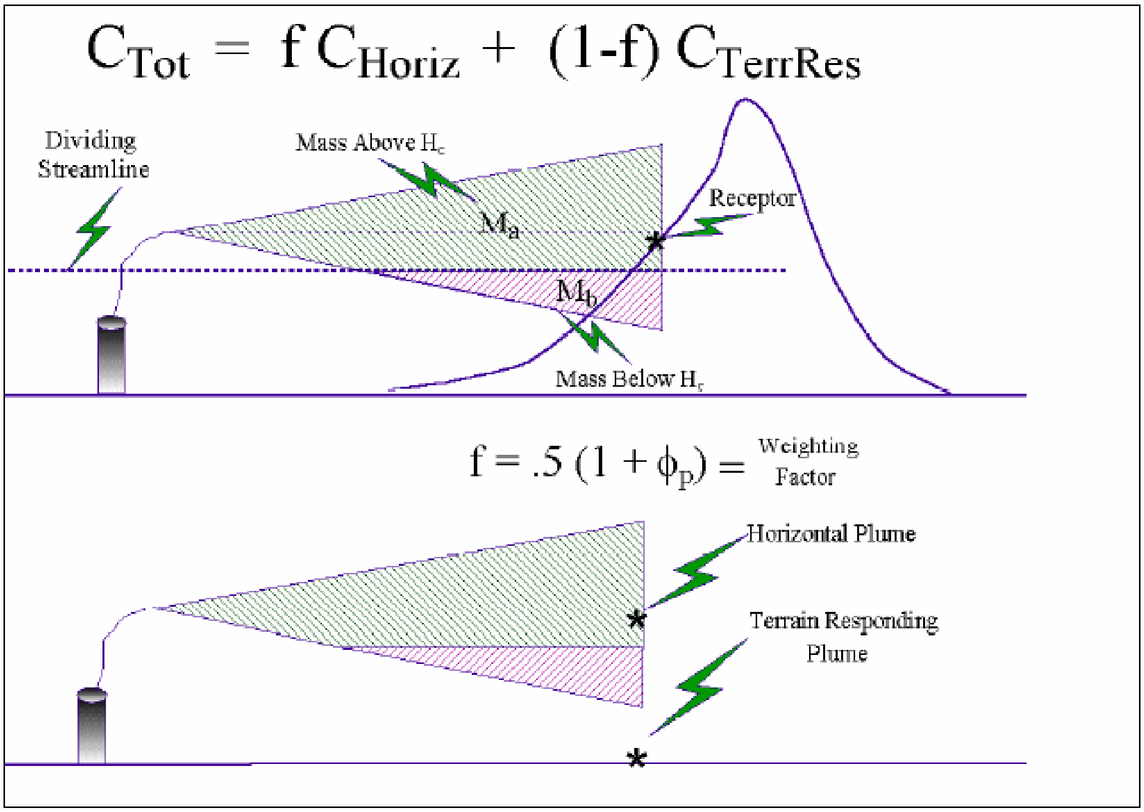

Figure 1 AERMOD's Terrain Plume Response (EPA 2004a)

AERMOD depends on information such as wind speed, atmospheric stability and plume height to predict how the air will move or disperse. AERMOD's terrain processor AERMAP handles terrain characteristics. This preprocessor is also responsible for calculating the terrain influence heights for the individual receptors to be used in AERMOD. It is necessary for airports to have level terrain for visibility and movement; therefore only flat terrain was evaluated in this study, limiting the need for AERMAP. The atmospheric stability is a way of describing the mixing properties of the air. Air under unstable conditions is turbulent in nature causing the atmosphere to be more of a homogenous mixture. Many of the meteorological requirements of AERMOD are used in the AERMET processor. AERMET has the ability to read large complex meteorological files in forms that are available from established sources such as Webmet, the meteorological resource center and the National Oceanic and Atmospheric Administration (NOAA). The important surface characteristics include parameters such as surface roughness, Monin-Obukhov mixing length as well as creating the vertical profile for the boundary layers. This preprocessor also has the ability to pass along certain key meteorological information that is also needed by AERMOD such as wind speed and direction, temperature and turbulence (MACTEC 2006).

The emission calculation procedures in AERMOD are well established and recommended by EPA so this effort is not to evaluate AERMOD but the manner in which AERMOD is being used to characterize dispersion from airport sources. In AERMOD a line source must be modeled as an elongated area source, or a series of volume sources (EPA 2004b). Since the majority of airport sources are not stationary sources, but a variety of complex mobile sources, it would be difficult for a model designed primarily for point sources to handle many of the complexities involved at airports. The EDMS emission factors are well established and accepted by EPA, and as such, only the model procedures are being scrutinized. Since AERMOD does not include an algorithm for line sources, roadways, runways, and taxiways, these are instead treated as continuous area sources (FAA 2004). In EDMS gates can be modeled as either an area source or a volume source. For this study all gates are volume sources because the emissions originate from a single discharge point. However, when the gate activity is represented by multiple points EDMS treats the gate activity as an area source. This evaluation is needed because there are no official EPA guidelines on how AERMOD should be used to model airport sources. The EPA has given FAA guidance on applying AERMOD in EDMS, but in an effort to maximize model accuracy the FAA is evaluating EPA's guidance and will refine the source characterization and dispersion assumptions where possible.

In theory, the incorporation of AERMOD, EPA's MOBILE 6.2, AERMAP, and AERMET should result in substantial improvements in EDMS accuracy, but corroboration using appropriate field measured data is desirable to substantiate this assumption and refine the manner in which airport emission sources are characterized using AERMOD. Although AERMOD has been validated for stationary sources, the dispersion algorithms of AERMOD have not been validated with regard to the many and varied sources found at an airport, which also includes area and line sources (EPA 1995). A 2004 study showed that the plumes from jet engine exhausts behave much differently than plumes from typical stationary sources. The extreme temperature of typical jet exhausts reach temperatures over 1000 degrees Kelvin, creating a strong temperature differential between the exhaust plume and the ambient air. This creates a strong buoyant energy forcing the exhaust plume upward. Another difference in the plume from aircraft is that it seems to be less dependant on typically important parameters such as wind speed and stability class. This initial study shows that temperature could be the dominant dispersion factor on aircraft emissions (Wayson, Fleming and Kim 2004). Complete sets of data, including measured concentrations and associated operational data are needed to evaluation EDMS and its ability to predict CO pollution concentrations. This study was designed to provide that data and the comparison of the collected data with the model's predictions.

CHAPTER 3 – METHODOLOGY

Site Location

It is important to understand how the CO sampling was implemented at Dulles International Airport to show the reliability of the measurement results and to understand the extensive amount of data collected during the sampling periods that made the analysis presented in this thesis possible. The Volpe Center, the FAA, and the University of Central Florida all had personnel onsite involved in the massive measurement and data collection process. These sections are presented to give the necessary background information on the project before the analysis of the Emissions Dispersion Modeling System (EDMS) can be presented. This data provided the basis for the analysis presented in this thesis.

In 2001, the FAA and Volpe Center initiated the process of identifying a suitable airport at which to conduct CO measurements for the purpose of beginning the EDMS verification. Specific considerations in identifying a potential airport were as follows:

- Located away from urban areas and other major sources of CO to minimize the influence of non-airport sources, not explicitly included in EDMS.
- Seasonal data was not a requirement since sampling would not be used for compliance issues. However, weather was still a major consideration for pollution distribution concerns. It was desirable to measure both stable and unstable cases, especially when associated with low mixing heights. Cases with low wind speeds, regardless of stability

are important because these will have the highest concentrations. Also, it was important that the sampling be performed when no precipitation was present since the effects of precipitation cannot be accounted for in EDMS.

- Measurements needed to be performed during peak aircraft activities at the study airport to increase the “CO-to-background” ratio. Furthermore, the airport must have sufficient operations to allow measured data to significantly exceed any background CO concentrations in the area since background concentration are not included in the model.

With these considerations in mind, Dulles Airport in Northern Virginia, near Herndon was selected as a suitable site to be used in this study. Sampling locations were identified to ensure the highest quality data could be collected with a minimum amount of resources. The locations of the air sampler units were carefully chosen based on three basic ideas. The first important consideration was a location that enables some samples to be captured up wind where possible. These samples are important to capture CO concentrations entering the airport area to serve as an indication of background concentrations. Dominant trends were predicted using historical wind data for the area during the month of January. The second objective was to be able to capture CO concentration indicative of different modes of aircraft operations, such as take off and approach. To do this some sampling locations were placed near and along runways (Appendix A Figures 23 and 24). The third governing idea was that sampling should occur where there is frequent human activity such as the terminal area. After exhaustive details of the airport were considered the study team identified 25 locations for sampling sites. The locations of the 25 air sampler units are shown on the map in Figure 2.

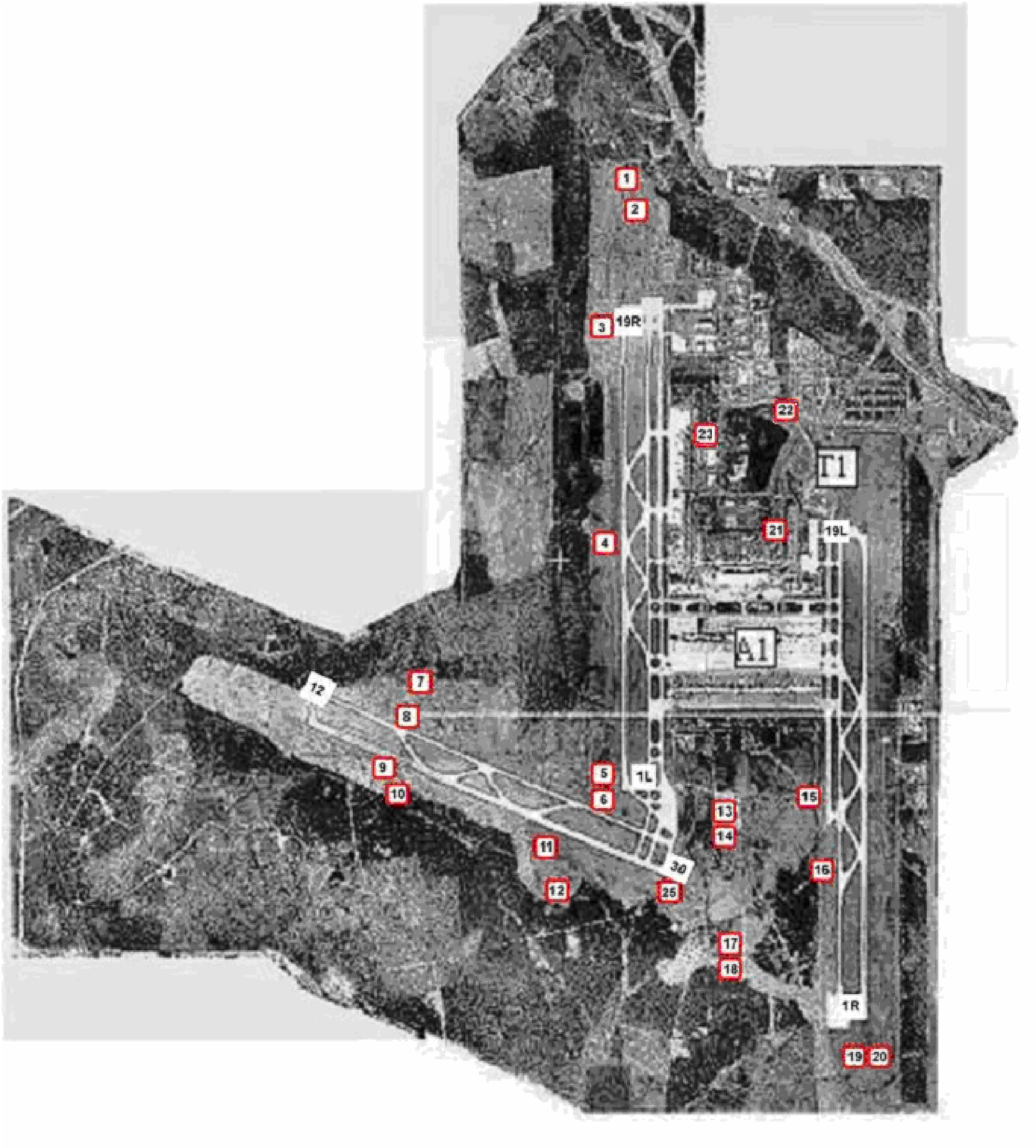

Figure 2 Layout of Measurement Positions (MWAA 1996)

Air sampling positions were discussed at length and placement was based on consideration such as wind direction and areas of expected high pollution concentrations. The upwind positions were used to determine the background CO concentrations during the measurement periods and the layout included flexibility so that there would always be an upwind location. The average concentrations from these positions are considered to be background levels during each sample period. This becomes important during modeling because EDMS does not take into account background concentration. To avoid obstruction interference air sampler units were placed at a horizontal distance of at least twice the height of any obstacle such as a building. A few additional locations for air sampler units were decided on based on the locations of expected higher pollution concentrations such as roadways and runways. Roadways and runways are typically large emission contributors and CO concentration information near them was thought to be important in the evaluation of aircraft source modeling. In these cases both upwind and downwind sample positions at multiple distances from the runway were employed. The downwind sample positions at multiple distances allowed for a determination of pollutant changes with distance from the source. This range of distances was expected to provide valuable insight to the dispersion performance of EDMS. Samples were also located and measured at the end of runways and near heavily traveled taxiways because they allowed for specific analysis of aircraft source modeling and concentration contribution. Meteorological stations were co-located with air sampler units at Site 2 and Site 13 (Figure 2). Landside traffic logging was conducted just to the east of Site 22 at Position T1. Personnel stationed in the ramp tower, Position A1 in Figure 2, conducted airside traffic logging to the north of the reference location.

Many of the sample positions used in this study coincided with EPA guidelines in legislation such as the National Environmental Policy Act and the Clean Air Act (NEPA/CAA) for measurement locations for modeling projects in air quality analysis. These locations involve human activity such as near the terminal areas, near short term parking, or adjacent to vehicular roadways (Figure 25, Appendix A). It was important to include locations where the general public has access. In addition to the air sample units, a non-dispersive infrared (NDIR) photometer was co-located at Site 13 (Figure 2) to serve as a reference quality check of the Minivol air samplers (Figure 32, Appendix A). The inlet of the NDIR and the co-located air sampler were within 6 inches of one another (Figure 26, Appendix A). Also located at the reference site was the base operational station used for the study. It consisted of a 30-ft storage trailer, which provided system power and charging capability, as well as equipment and data storage as shown in Figure 27 in Appendix A. Part of this equipment was a second NDIR used for bag analysis. The deployment of a co-located reference system provided an extra measure of quality control that was specifically included by a review of EPA sampling protocol and included in the study test plan.

Instrumentation

Installation of Air Samplers

The air sampling units were installed in one of four configurations, pole-mounted (Figure 28, Appendix A), tripod-mounted (Figure 29, Appendix A), fence-mounted (Figure 30, Appendix

A), or light-post-mounted (Figure 31, Appendix A). Where applicable, rebar was driven into the ground at each position to allow for easy location of the specific sampler, and to facilitate later site surveying if a follow up study was desired. Each sample bag canister was labeled with the particular site number it was designated, as well as an L (left) or R (right) designator. The right Tedlar bag was always the first one filled during each two-hour sampling period.

Air Sampling Instrumentation

The air sample units utilized in the study were designed around a calibrated pump and two Tedlar bags. These units, which were deployed at the 25 predetermined locations around the airport, were pre-programmed for automatic operation, weather resistant, battery operated, and easy to use. The units were Airmetrics MiniVol portable Tedlar bag sampler units. These portable sample units allowed collection of ambient gaseous samples in 5-liter Tedlar bags (Figure 32 in Appendix A shows a close-up view of the Minivol air sample unit as it was deployed in the field). The Tedlar material is essentially non-reacting, and as such, greatly reduces the potential for sample contamination. Although the MiniVol is not an EPA reference method, the flow control units were designed and developed jointly with the EPA and the samplers have been successfully used in numerous studies (Airmetrics 2001). In fact, the EPA owns many of these units and has used them on several of their own projects, and has specifically concurred with their use for this study as part of their review of the study's test plan. The MiniVol uses a programmable timer to control a pump that draws air at a predetermined sample rate to control the time to fill a single bag. The battery-powered unit fills the Tedlar bags with ambient air samples that can be easily analyzed to determine CO concentrations. The sample unit has two Tedlar bags that can be filled one at a time or simultaneously. How fast a bag is filled, and when each bag is filled, is programmed by the user. In this study, the unit was prepared such that one bag was filled each hour, with both bags being filled over a consecutive two-hour time period. This provided one-hour averages allowing direct comparison to modeled concentrations using the EDMS.

CO Analyzer

Two Monitor Labs Model 9830 non-dispersive infrared (NDIR) photometers were utilized to measure CO concentrations as shown in Figure 33, Appendix A. One unit was used to measure the CO concentration from each Tedlar bag. As an added level of quality assurance, the other unit was co-located at Site 13 with an air sampler, and setup to measure CO concentrations continuously in real time. These continuous samples were converted to one-hour samples for comparison with the concentrations measured in the co-located Tedlar bags. In compliance with EPA's suggested methodology of placing co-located samplers no more than 4 meters apart from each other, the inlet of the Teflon tubing for the NDIR was within about 6 inches of the inlet of the co-located air-sampling unit. The Model 9830 is an approved EPA reference method and can accurately and reliably measure low concentrations of CO. The NDIR measures the absorption of infrared radiation (IR) at a wavelength of 4.7 micrometers to determine CO concentrations. An IR source is located at one end of a 5-meter folded path length filled with ambient air and the absorption of IR is measured at the other end. The amount of IR is compared to a sample path filled with nitrogen, which does not absorb the IR at the critical wavelength. A comparison of the absorbed IR provides a measure of the concentration of CO in the ambient air. In addition, a gas filter correlation wheel facilitates rejection of interferants and a narrow band-pass filter helps to ensure only the critical wavelengths are measured. This design allows for more accurate determination of ambient air CO concentrations. Other key specifications of the Monitor Labs 9830 include:

- a fixed sample rate of 1 standard liter per minute (SLPM) which meets EPA requirements for ambient sampling;
- auto-ranging display and output from 0 – 1 to 0 - 200 parts-per-million by volume (ppm_v) with a resolution of 0.01 ppm_v (for consistency with EPA requirements, measurements were performed in appropriate ppm_v ranges);
- a lower detectable limit of 0.05 ppm_v or 0.2% of full scale (whichever is greater), with a precision of 0.1 ppm_v or 1% of reading (whichever is greater); and
- very low interference of water vapor and carbon dioxide (CO_2).

Ultra-pure zero air and multiple concentrations of calibration gas were purchased to allow both a five point complete calibration of the range used (0 to 10ppm) and then on a daily basis zero and upscale calibrations were performed. The linearity of the NDIR was checked by use of multi-point calibrations. The drift of the measurement equipment was quite small, less than two tenths of a part per million. This drift was corrected daily and was accounted for in the final reported measurement concentrations through a linear regression analysis. Input to the NDIR was provided from a vented output manifold that ensures the gas entered the NDIR is at ambient pressure.

CO Concentrations

The Monitor Labs NDIR units were factory calibrated prior to arrival at the test site. In addition, certified calibration gases were brought to the site for detailed 5-point calibrations at the start and end of the study and for daily zero point (ultra-pure zero air with 0 ppm of CO) and span gas (near 10 ppm CO) calibrations. The 5-point calibration is used to determine the linearity of NDIR response over the measurement range (0-10 ppm for this work). The following calibration gases were used for the five-point calibration: 0.0 ppm CO, EPA cert. ultra pure carrier gas, “zero gas”, 2.8 ppm CO, 5.4 ppm CO, 8.4 ppm CO, and 10.2 ppm CO, “span gas”. The five-point calibration procedure was conducted prior to the first day of the study. A simpler calibration was performed during the morning of each day of testing. This consisted of setting the 0.0 ppm value on the NDIR unit by supplying “zero air” to verify the unit “floor”. The 10.2 ppm “span gas” was then supplied to the unit and the level indicated by the NDIR recorded and gain changed if necessary. At the end of the test day, the same process was performed except that the NDIR calibration was not changed but the indicated values were simply recorded. These final values gave an indication of how much the NDIR had “drifted” throughout the day. The recorded levels, using the calibration gases, were used to determine the calibration adjustment by constructing a curve fit of actual concentration versus NDIR indicated concentration. The adjustment was then applied to the concentrations measured (indicated by the NDIR) throughout the day.

Airside Activity Log

A manual logging system was utilized to record airside activity on the airport. Observers were positioned in the airport ramp tower (Figure 2, Position A1) at locations that allowed for a 360 degree view of airside activity at the airport. These observers used a log sheet (Figure 34, Appendix A) to record detailed aircraft/flight parameters such as: arrival runway, arrival taxiway, arrival taxi time, gate number, gate in time, aircraft tail number, aircraft type, airline, related GSE and APU activity, gate out time, departure taxi time, departure taxiway designator and departure runway.

Landside Activity Log

A manual logging system was utilized to record landside activity in both directions on the Dulles Access Road. One observer was positioned to log eastbound traffic (exiting airport) and a second observer was positioned to log westbound traffic (entering airport). These observers used a log sheet as shown in Figure 35, Appendix A, to record vehicle types over consecutive fifteen-minute start/stop times. In addition, vehicle speed was periodically sampled using a Doppler Radar Gun.

Meteorological Instrumentation

In addition to the air sampling instrumentation, two Qualimetrics Transportable Automated Meteorological Stations (TAMS) were deployed adjacent to Air Sampling Site 2 (Figure 36, Appendix A). The sensors of the two units were positioned at a height of 5 ft and 15 ft. The TAMS units were setup to measure temperature, relative humidity, wind speed and direction, and ambient atmospheric pressure in one-second time intervals. The data is captured in an HP 200 LX palmtop computer. With the TAMS units, wind can be measured from a stall speed of 2 mph, to a maximum of 55 mph, with an accuracy of 1 mph or 5% of the range (whichever is greater) and a resolution of 1 mph. Wind direction can be measured a full 360 degree with a root mean standard error of 18 degrees and a resolution of 10 degrees. Temperature can be measured from –9 to 110 degrees Fahrenheit with an accuracy and resolution of 1 degree. Relative humidity is accurate within 3% with a resolution of 1%.

Other more precise anemometers were also used. These units consisted of RM Young u-v-w wind speed and direction sensors connected to a Campbell Scientific datalogger (Figure 37, Appendix A). At the end of a measurement day, the files were transferred to a laptop computer. The stall speed of these units was 0.1 mph and measured the wind direction in all three orthogonal coordinates.

Site Survey Instrumentation

A site survey was conducted using a differential Global Positioning System (dGPS) which was designed around two single-frequency (commonly referred to as L1) NovAtel® Model RT20E GPS receivers and two GLB® Model SNTR 150 transceivers which facilitate remote communication between the two GPS receivers. The two 25 Watt GLB transceivers were tuned to a frequency of 136.325 KHz. As deployed, one of the NovAtel/GLB combinations acted as a base station (Figure 38, Appendix A) and the other combination as the roving unit (Figure 39, Appendix A). These two combinations worked together to provide a relative, three-dimensional, positioning accuracy of 20 cm. The dGPS system also contained a Graphical User Interface (GUI) and supporting software that was tailored for use during aircraft noise certification tests. The system is documented in (Fleming 2001). The dGPS system was used to determine a coordinate system for the measurement instrumentation and the airfield. This coordinate system was also used in data processing and analysis. The coordinate system used was defined with the positive X axis running under the departure centerline from Runway 12 (Figure 51 and 52, Appendix A), the positive Y axis to the north, and the positive Z axis vertically up. All measurement sites, both air samplers and meteorological stations, used this coordinate system.

Measurement Site Survey

To support the entry of site geometry to FAA's EDMS, the site was surveyed to obtain three-dimensional position information of all important site features. Differential GPS measurements were performed over the course of the day on January 9th. The roving unit of the dGPS instrumentation was used to accurately measure the relative position of the 25 sampling units, as well as the major roadways in/out of the airport terminal area (Figure 50 in Appendix A shows this data graphically).

Other Instrumentation

Various types of support instrumentation and supplies were integral to the success of the study. Such instrumentation included calibration equipment to measure the intake flow of the bag samplers, gas regulators for connection to ultra-pure zero air and calibration gas, a laptop computer for communication with the instrumentation, certified gases, Teflon tubing, and associated miscellaneous instrumentation. In addition, for both, technical and safety reasons, Motorola i700plus cell phones with Nextel's Group Calling Mode were utilized. This Mode of communication allowed for walkie-talkie like operation/convenience with unlimited range since the units utilize the cellular system. The i700s were supplemented by hand-held Motorola Talkabout Model 250 family band radios. Because of their limited range the 250's were used primarily by personnel at a particular location, but within several hundred feet of one another (e.g., personnel at the landside logging location). Also, a single digital watch served as the master clock for time synchronization of all instrumentation. Several sets of binoculars were utilized for logging aircraft activity.

Field Measurements

The University of Central Florida personnel arrived on Thursday, January 3, 2002, and prepared all of the instrumentation for field deployment. This included unpacking of instrumentation, preliminary calibrations, checking of instrumentation functionality, sighting of specific measurement positions and coordination with local personnel. The Volpe Center measurement team arrived Sunday, January 6, 2002 to complete the site installation and instrumentation preparation that continued into the next morning leading to a final meeting in the afternoon. Measurements were then conducted for three days during the six peak hours of the day. Measurements ran from January 8th to January 10th 2002.

During a typical field measurement day the air sampling units were programmed to initiate sampling at 0800 and continue for one hour, until 0900 and filled a 5 liter Tedlar bag. As discussed previously, each unit was equipped with two independent sampler canisters containing Tedlar bags. Immediately following the 0800 to 0900 sampling period (right canister) the units were programmed to switch to the second sampler canister (left canister) and initiate sampling (0901 to 1001). Similarly, two, sequential one-hour sample periods were programmed to occur between 1200 and 1401 and subsequently between 1600 and 1801. Consequently, the entire framework for a typical measurement day was structured around these three two-hour sequential sampling periods, purposely selected to capture peak periods of airside operations.

Team Organization

The study team was organized into three groups, each with unique responsibilities: First an air sampling and meteorological group; second an airside activity group; and third a landside activity group. The test director oversaw all groups during measurements. The air sampling and meteorological group was responsible for checking air sampler and meteorological system functionality, as well as replacing the filled sampler canisters after each two-hour measurement period. An additional individual was always on site at the trailer and was responsible for the two NDIR analyzers, and the co-located air sampler and meteorological stations. The airside activity group was responsible for logging all airside activity in detailed aircraft logs. The landside activity group was responsible for logging all vehicle traffic.

Measurement System Setup

For the air sampling and meteorological group, system setup typically included deployment of evacuated canisters and replacement of sampler battery packs with newly-charged batteries. For convenience, this was performed on the night prior to measurements, thus allowing for the 0800 sampling period to begin without the need of personnel intervention each morning. Overnight deployment was also facilitated by the fact that the majority of the samplers were positioned within the bounds of the highly secure airport property. The sampling group was also responsible for calibration and operation of the NDIR, including the performance of a 5-point calibration of the NDIR units to check for non-linear response. More detailed calibrations were conducted in the field prior to the initial day's measurements and after the final day's measurements. At the start and end of each measurement day, a 0.0 ppm calibration of the NDIRs was performed, as well as a 10.2 ppm span gas check. Each morning of measurements the sampling group also setup and initiated meteorological data collection.

Airside activity group personnel were required to be onsite at 0700 each morning, at which time they were escorted to the ramp tower (Figure 40, Appendix A) and positioned for data collection, to identify aircraft, take taxi times, count and identify ground support equipment, etc. Similarly the landside activity group was in position at the Rudder Road overpass, approximately ¼-mile to the west of the intersection of Route 267 and the Dulles Airport Access Road, (Figure 41, Appendix A) at 0730, and data collection was initiated at 0745. For the counting of eastbound traffic (exiting airport) an observer was positioned atop the Rudder Road overpass. For the counting of Westbound traffic the observer was positioned at the base of the Rudder Road overpass. The observer atop the overpass was also responsible for logging local airport traffic on the overpass.

Measurements

During the three, two-hour periods of measurements, the air sampling group readied the canisters and Tedlar bags for redeployment in the field. This involved NDIR analysis of the previously captured sample and subsequent evacuation of the Tedlar bags as shown in Figure 42, Appendix A. Analysis of the captured sample required the continuous sampling of the contents of the

Tedlar bag until a stable CO concentration level on the digital display of the NDIR was observed (Figure 43, Appendix A). The concentration level was then recorded on diskette as well as manually in a logbook. Approximately 30 minutes before the end of a sampling period, each of the three, two-person teams would depart for their respective sample sites, retrieve the completed samples and place the new canisters with evacuated Tedlar bags and ensure the unit was ready for the subsequent sampling period (Figure 44, Appendix A).

Approximately 15 minutes prior to each sample period the group located in the ramp tower would begin logging airside activity in the ramp/taxi area. The logging was performed using the standardized log sheets and was facilitated by binoculars as needed (Figure 45, Appendix A). Unfortunately, the ramp tower did not offer an adequate view of the southern side of the airside terminal area due to the terminal blocking some aircraft activities. As such, a separate observer was positioned near the trailer location. The airside logging included aircraft activity as well as any activity of ground support equipment (GSE) at the gate location (Figures 46-49, Appendix A). In many cases it was difficult to determine if the GSE were servicing an aircraft or simply parked next to it. In these cases, good engineering judgment was used. For example, times were not recorded for GSE that appeared to be simply parked in the vicinity of a gate. Any activity from construction vehicles, which was minimal, was not logged.

Measurement System Dismantling

At the conclusion of each measurement day, the air sampling canisters were retrieved, new canisters with evacuated Tedlar bags were deployed, and the battery pack was changed on each air sample control unit. The retrieved canisters were brought back to the analysis trailer where CO concentrations were measured. In addition, the four meteorological stations were retrieved, with the stored data being downloaded to a laptop computer. Personnel in the ramp tower were escorted, by car through the secure area; data log sheets were collected, any issues were discussed and resolved and plans for the subsequent day of measurements were reviewed. Likewise, personnel at the Rudder Road Overpass met back at a control location and provided log sheets to the test director, any issues were discussed, and the schedule for the subsequent day of measurements was reviewed.

EDMS Input

The three day measurement trip resulted in an enormous amount of data that needed to be sorted, organized and entered in electronic format. Despite all of the information collected some additional data necessary was received through phone and email correspondence with airport personnel. When information was not available certain assumptions had to be made. The airport layout was configured using the dGPS information previously discussed. Each piece of the airport was given an x and y coordinates to let EDMS know the layout of all the important features of the airport. EDMS requires coordinates be entered for all roadways, parking lots, buildings, runways, taxiways, and gates that need to be considered during the modeling process. The EDMS inputs are described in detail with all assumptions and pertinent information documented in the following sections.

Gates and Buildings

The gates were given a single x and y value and represented as just a single point (Figure 3). The gates were label either odd or even and a letter designated by the airport terminal A, B, C, D or T. This simplification of even and odd gates limited the number of gates to be entered into EDMS since the distance between the number gates was minimal and the travel path of the aircraft would remain the same. Gate information had to be entered for every aircraft entering or leaving during the study. All gates were given a height of 1.5 meters, the minimum height for the gates to still be considered a source of emissions. As stated before all air sampling units were placed at least twice the distance from any obstruction as the height of the obstruction. This was done to minimize the effects of the obstruction on the receptors. This minimization of obstruction interference made the building locations effects on CO concentration minimal and therefore their locations were not included in the model.

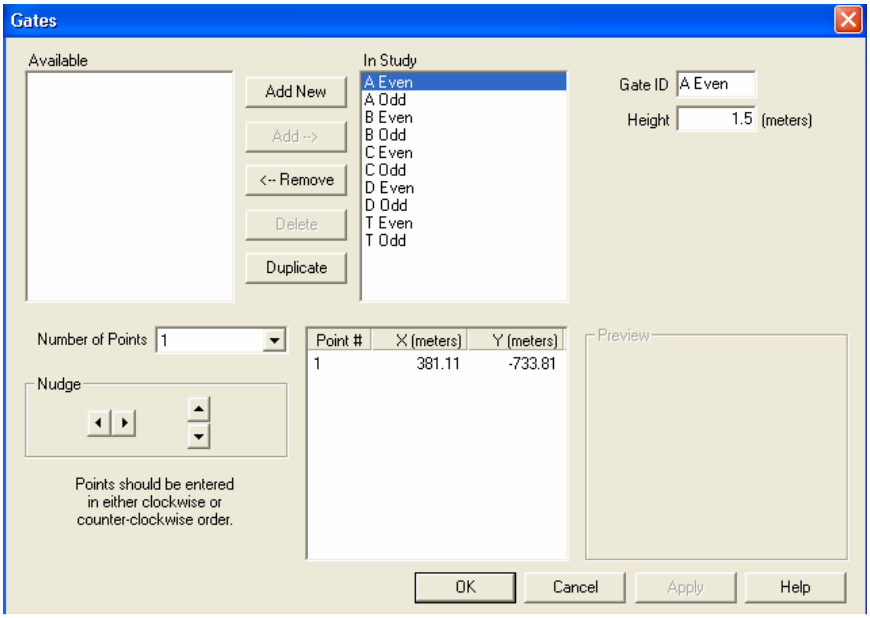

Figure 3 EDMS Screen Capture of Gate Inputs

Runways and Taxiways

Dulles International Airport has three runways: 12-30, 19L-1R, and 1L-19R. The end points of the runways were entered as x and y coordinates as well as the values for the peak length of the runway (Figure 4). The peak length accounts for aircraft queue before taxing and takeoff. When runways are designated for an aircraft they are entered as a single number, for example 19L, to give direction to the arriving and departing aircraft. The peak queue time was set as zero because individual queue and taxi times were entered for each aircraft.

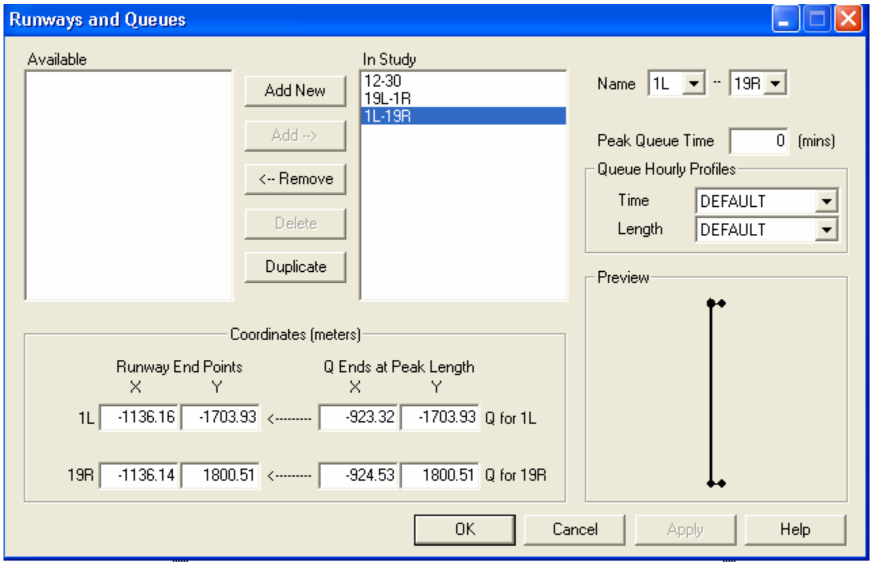

Figure 4 EDMS Screen Capture of Runway Inputs

All taxiway are 20 meters wide and are set as such in EDMS. It is assumed that all aircraft will travel down the taxiway at a speed of 30 mph. This is a typical speed at which to leave the gate and approach the runway. The taxi time is calculated based on the speed and length of the taxiway. The taxiways are designated by 2 sets of x and y coordinates creating a line segment that EDMS knows to be 20 meters wide (Figure 5).

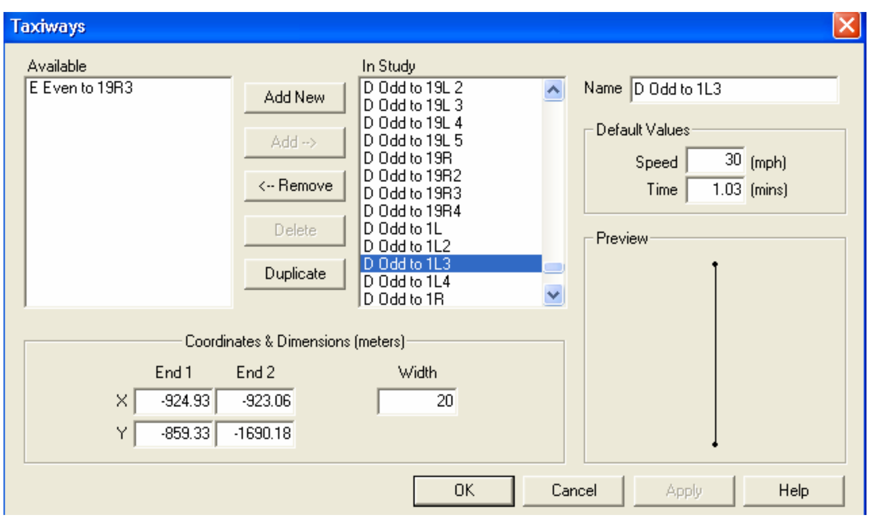

Figure 5 EDMS Screen Capture of Taxiway Inputs

Each roadway had to be entered in sections to approximate the curve of the road. Each section of each roadway has a set of x and y values forming a line segment (Figure 6). The height of all roads was entered as zero meters assuming the airport is relatively flat. Therefore a width of 6 meters and a height of zero were assigned to all roads. Speeds were only collected for one day. These speeds were averaged speeds for each hour to be entered into the model and applied to the entire study. Mobile lounges were modeled as roadways and are discussed in greater detail in the Mobile Lounge Section.

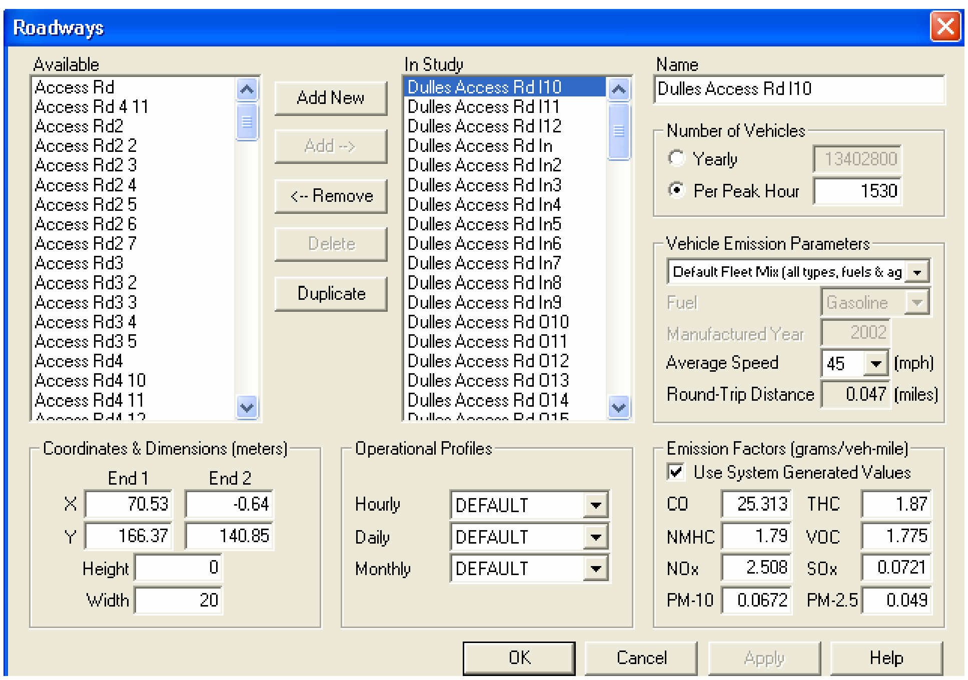

Figure 6 EDMS Screen Capture of Roadway Inputs

Seven parking lots were modeled in EDMS with several x and y coordinates to accurately depict the area of the parking lot (Figure 7). All parking lots were modeled as 1 level with an emissions release height of one meter. Mobile6.2 is included in the model and uses a default fleet mix of all types of vehicles, fuels, and ages to determine emission factors in the parking facilities. No estimates of vehicle idling times were available for this research; therefore the EDMS default idle time of 1.5 minutes was used throughout the emissions modeling process.

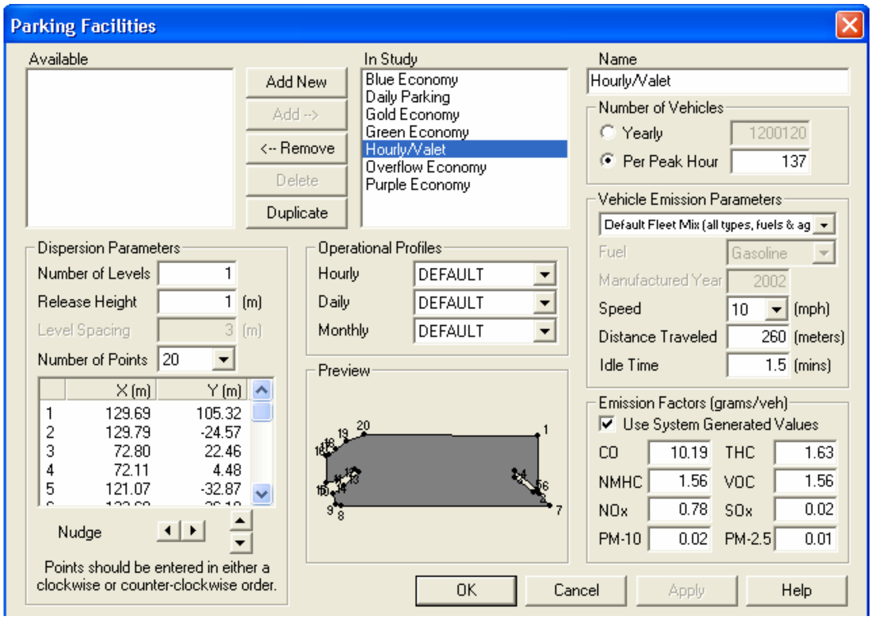

Figure 7 EDMS Screen Capture of Parking Facility Inputs

Stationary Sources and Training Fires

Data in this category includes any type of stationary source on the airport property, such as power plants, incinerators, fuel tanks, solvent degreasers, or surface coating operations as well as training fires. Dulles personnel verified that no training fires were conducted during the time period of the study, January 8 through 10, 2002. The stationary sources in operation at Dulles airport were limited to four natural gas fired boilers. The operations of these boilers remained constant throughout the study period. The boilers described in greater detail in the EDMS Inputs Section including their exhaust volume per hour (Figure 8).

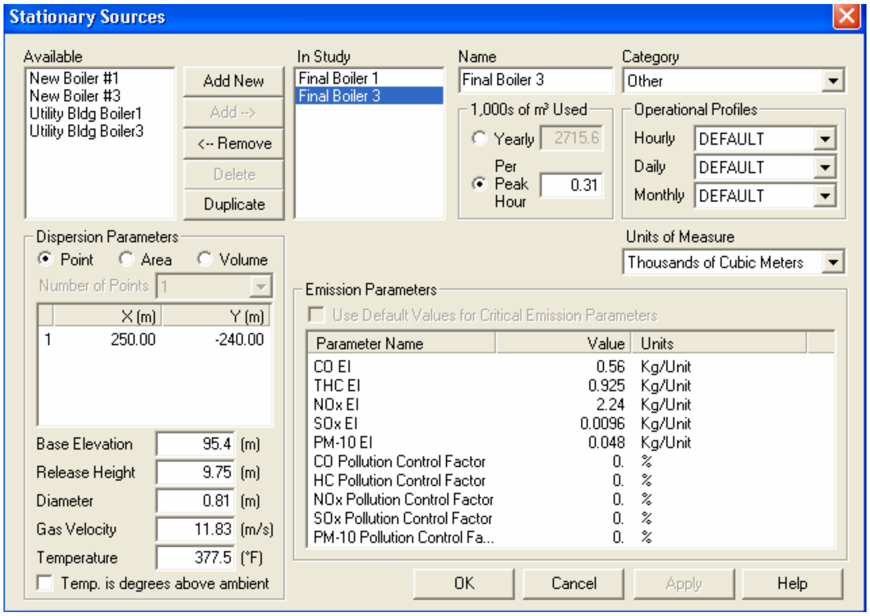

Figure 8 EDMS Screen Capture of Stationary Source Inputs

Aircraft Information and Operation

"Emission rates from aircraft are a function of aircraft mode (idle, approach, climbout, and takeoff), time in mode, fuel use, and engine performance" (Wayson and Bowlby 1988). The aircraft mode, 4 stage cycle can be generalized, however the idles time vary greatly depending on airport and number of flights as well as other unforeseen delays (Woodmansey and Patterson 1994). This makes the idle time, also known as the queue and taxi time the most variable parameter and thus the most detailed entry in the aircraft time in mode section. Other parameters that may effect aircraft emissions include aircraft maintenance, aircraft weight, and thrust settings for aircraft modes (Woodmansey and Patterson 1994). The information for this study was gathered by hand in aircraft logs and was then entered into a spreadsheet for record keeping and ease of use. Where available, these data included aircraft information such as arrival runway, arrival taxiway, arrival taxi time, gate number, gate in time, aircraft tail number, aircraft type, airline, related GSE and Auxiliary Power Units (APU) activity, gate out time, departure taxi time, departure taxiway designator and departure runway. The aircraft data was incomplete for many aircraft but using several outside sources of information, engineering judgment, minimal assumptions, and considerable effort, the information was entered into EDMS. The Department of Transportation's Bureau of Transportation Statistic's Airline Service Quality Performance (ASQP) database, the official airlines guide (OAG), IAD Back Tail Numbers, Find Aircraft software, UNA Aw2 Export database, airline fleet mix, and conversations with airline personal were used to supplement missing operational data. These sources supplied various information included flight identification, aircraft tail number, airlines, aircraft taxi times, arrival times, departure times, engine type, aircraft type, as well as other information. This information allowed for more precise modeling of the specific aircraft/engine combination within the model. However in some cases not enough information was available or could be determined (either through field logs or outside sources) to determine the specific aircraft model. In these cases, if an airline was known, the fleet mix data from the carrier were used along with aircraft distribution for that hour to determine the most likely possibility for the aircraft in question. In some cases this was relatively simple; Jet Blue for example, only has one type of aircraft, Airbus 320's. If the airline was not known, then the aircraft distribution was used to determine the most probable aircraft based on the mode method, which represented only 1.8% of the data. For these aircraft the default engines had to be used, and this was noted under the aircraft identification since no tail number was present. After the aircraft was determined, the specific engine had to be identified. This information was entered into EDMS from the aircraft logs and identified by tail number to ensure no duplicate aircraft were entered (Figure 9).

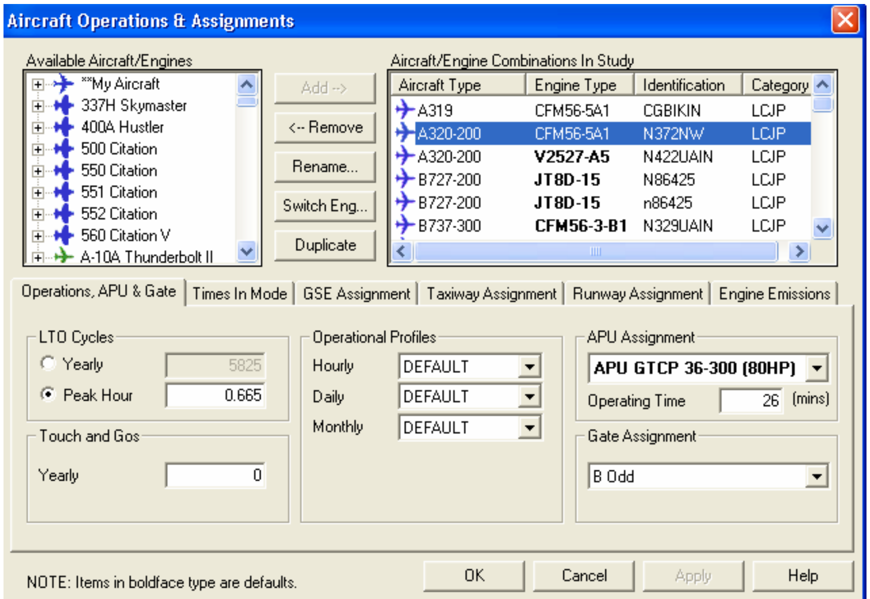

Figure 9 EDMS Screen Capture of Aircraft Operations Inputs

This study considered all aircraft in a specific one hour time period and included them individually in the input. Therefore each landing takeoff (LTO) cycle for each aircraft could be a maximum value of one. The value of one would indicate that the plane arrived and departed in the same hour. However the runways, taxiways, and queue and taxi times associated with departure and arrival are different. Therefore if an aircraft took off and landed in the same hour it would be modeled as two separate aircraft with a fraction of the landing take off cycle used for the peak hour. This fractional landing take off cycle was found to be 0.665 for departure and 0.335 for arrival. These fractions are applied to each aircraft to tell EDMS how much of the LTO cycle was completed in the peak hour being modeled (Figure 9). There were no touch and gos during the studied time frame at Dulles so all values for touch and gos are zero. The approach angle for all aircraft utilized a default value of 3 degrees. The taxi and queue times were entered for the aircraft when available (Figure 10). As noted before the taxi and queue times vary significantly for arrivals and departures and therefore they must be considered separately. The taxi and queue time will be discussed in further detail in the scenario section, as a different approach was used for each methodology.

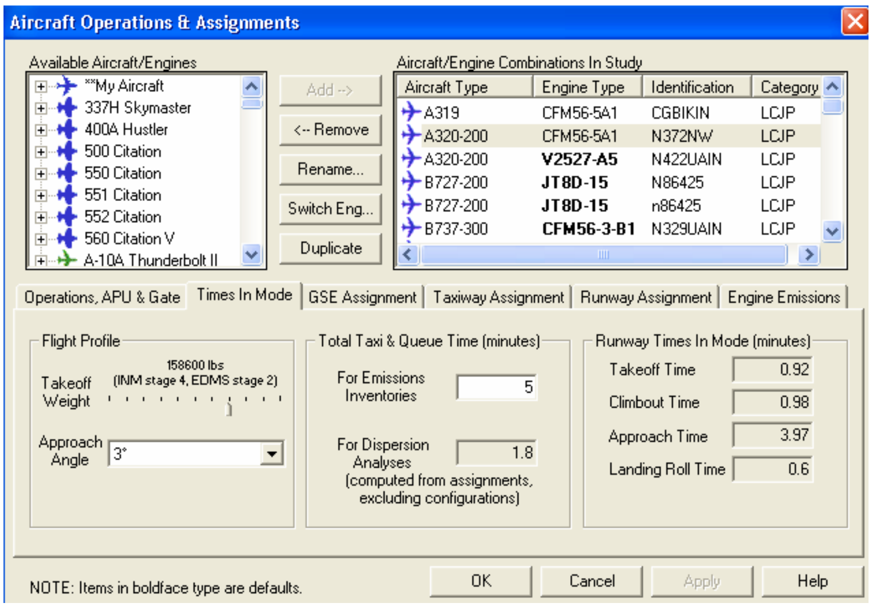

Figure 10 EDMS Screen Capture of Aircraft Times in Mode Inputs

Each aircraft input required a gate assignment in EDMS to define the aircraft path start and end points. Figure 9 shows the gate assignment while Figures 11 and 12 show the path the aircraft must travel including gate to taxiway and taxiway to runway path. When gate information was unknown or could not be identified it was entered based on the airline. Particular airlines use the same gates for all of their aircraft arriving and departing. In cases where the gate was unknown and so was the airline then the gate was assigned based on the weighted average of the gates that were used during that particular hour of the study. Since it is assumed that an aircraft will leave and depart from the same gate one weighted average was calculated for each hour of the study and applied as necessary. While aircraft are located at the gate they typical use Auxiliary power units (APUs) to provides lighting and sometimes air conditioning/heat as needed. APUs and their times of operation were also needed for each aircraft in EDMS (Figure 9). The APUs were entered directly from the log sheets where available. However when the APUs were unknown they were selected according to aircraft assignment. Individual aircraft types tend to have certain APUs types

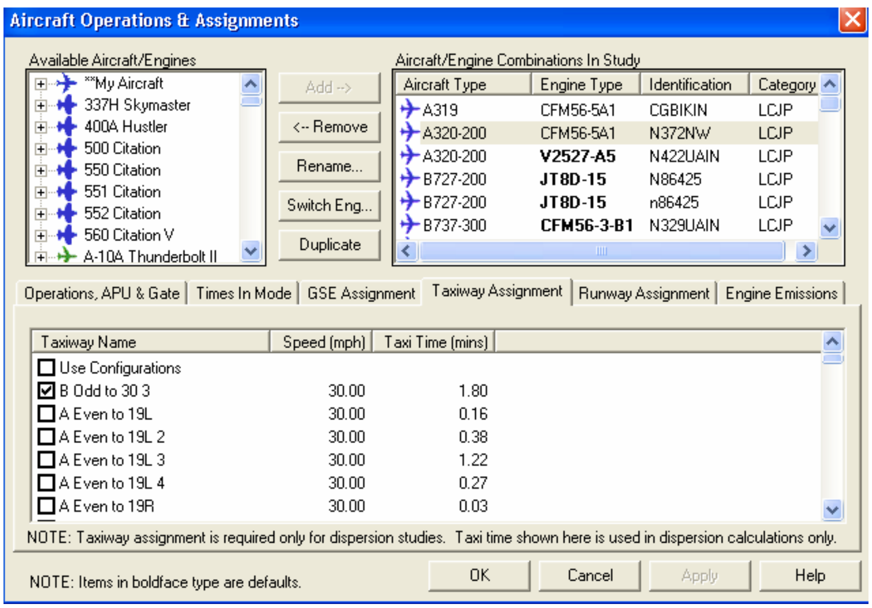

Figure 11 EDMS Screen Capture of Aircraft Taxiway Assignments

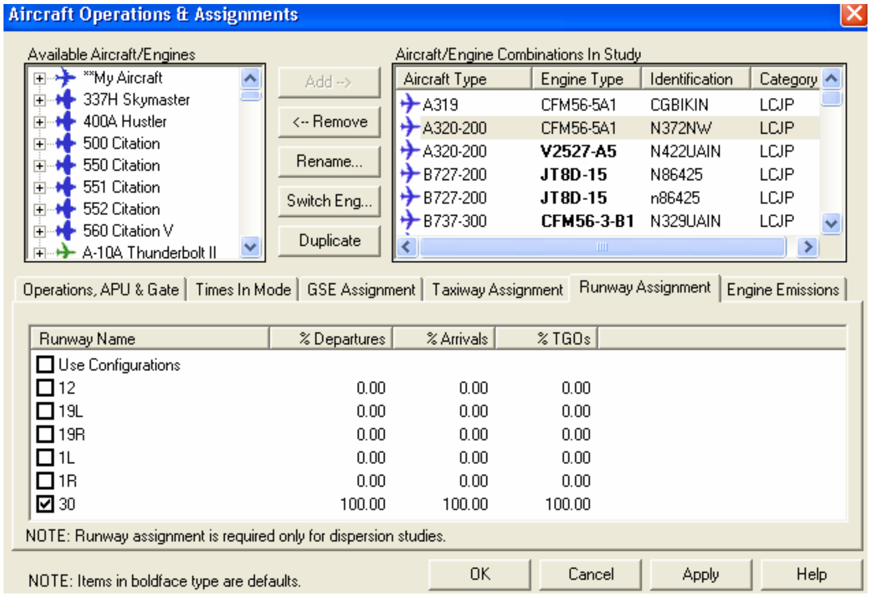

Figure 12 EDMS Screen Capture of Aircraft Runway Assignments

The ground support equipment for each aircraft was also entered into EDMS as available (Figure 13). When the information was unavailable the GSE activity was modeled based on information from the airlines. A representative from a major airline was able to provide the following guidance related to GSE use:

- Most airlines assume three categories for aircraft: narrow bodies (MD80s, 727s, 737s, 757s, etc.), wide bodies (747, 767, 777, etc.) and turboprops/RJs. In all three cases the goal is to have all luggage unloaded and on its way to the terminal within 20 to 25 minutes.
- For each narrow body, an airline will typically deploy 1 tow tractor or tug, 2 baggage tractors, and 2 cargo belt loaders (Note: one baggage tractor and one cargo belt loader will be deployed at the front cargo hold and one at the rear cargo hold).

- For each wide body, an airline will typically deploy 1 tow tractor or tug, 3 baggage tractors, 1 cargo belt loaders, and 2 container loaders (Note: one baggage tractor and one cargo belt loader will be deployed at the bulk storage/small bin, for loose luggage; and the other two tractors and two container loaders are deployed at the two bin storage areas).
- For each turboprop/RJ, an airline will typically deploy 1 oversized baggage tractor to be used for towing the aircraft and 1 baggage tractor.
- The only other GSE that would be deployed would be for fuel, food and servicing. These services are all contracted out and not handled by the airlines so are only used when specifically listed.

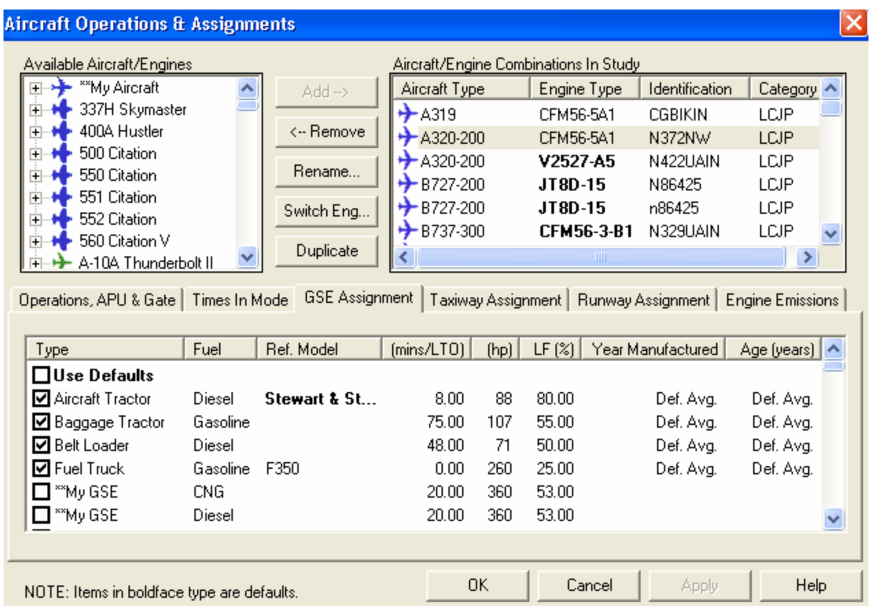

Figure 13 EDMS Screen Capture of Aircraft GSE Assignments

Aircraft log data was deficient in information regarding taxiway and runway assignments for many of the arriving and departing flights. In many cases this information was not known because these logs were not available from the airport. The airport did have available the particular runway configurations that were active for specific spans of time during the measurements. Most configurations called for multiple runway operations with little or no information about taxiways, therefore in many cases a judgment had to be made. The known number of each runway was counted and weighted as a percent of the total known runways. The percent was then applied to the number of unknown runways during a specific hour to determine a runway distribution for the unknown runways. This distribution was applied based on smaller time periods within the hour. This application provided similar runways in the same time period. The taxiways were based on the path from the gate to the specified runway. However there are many paths to get from a specific gate to a specific runway, so these were assigned as detailed as possible on the frequency of path taken.

Source Data for Two Scenarios

In preparing source input data for EDMS, there are two ways in which these data can be entered using standard EDMS defaults or using the best data available detailed approach.   The two scenarios analyzed both utilize detailed information but with two slightly different approaches. The first scenario is the EDMS method that would mostly likely be used in practice. This detailed practice approach utilized specific airport information that would be available from the airport such as posted speed lists and generalized taxi and queue times. The second approach is the detailed research approach, which utilized the most detailed information available from observer logs and Dulles personnel. Both approaches are described below for all necessary EDMS input.

Aircraft and GSE

Aircraft and GSE: Detailed Practice Approach

Actual aircraft information utilized in this approach included gate assignments, taxiway assignments, and runway assignments. The GSE defaults were used as inputs into EDMS. The times in mode (taxi and queue) were entered as the Dulles averages of 5 minutes for all arriving aircraft and 13 minutes for all departing aircraft.

Aircraft and GSE: Detailed Research Approach

Actual aircraft fleet and activity data were again used as input values. Aircraft information included landing/take-off (LTO) cycles, times in mode (taxi and queue), gate assignment, taxiway assignment, and runway assignment. For each hour of the study the known arrival taxi and queue times were averaged and this average was then applied to the arriving aircraft with unknown taxi and queue times. The departure taxi and queue times were also averaged for the known aircraft each hour and applied to the departing aircraft with unknown taxi and queue times. GSE activity was entered where known and where it was unknown the input was based on the aircraft type, which greatly helped in correctly choosing the appropriate service vehicles.

Parking Lots

Parking Lots: Detailed Practice Approach

Information about the traffic volumes in parking lots was provided by Dulles personnel and utilized directly as EDMS inputs. The posted parking lot speed of 15 mph was applied to all parking lots for this approach.   The distance traveled for each parking lot was determined by using half the distance of the length of the parking lot. Half of the distance is assumed because this should be the average distance traveled for the cars in the lot.

Parking Lots: Detailed Research Approach

Dulles International Airport personnel provided vehicle counts by hour for each of the parking facilities on airport property. Personnel also provided estimates of vehicle speeds and routes while in each lot. Vehicles were estimated to travel 20 mph in the parking areas and travel about 1 mile to find a parking spot. The daily lot is smaller than the other parking areas and thus the estimated travel distance to find a parking spot was only half a mile. This actual lot usage information was utilized as inputs into EDMS.

Roadways

Roadways: Practice Detailed Method Approach

It is difficult to determine the volume of vehicles on the roadway during a given hour and EDMS does not maintain standard default values for roadway activities, thus the research observed traffic volumes were utilized. The posted roadway speed of 35 mph was used for each of the roadways modeled. The default vehicle fleet mix was used in Mobile6.2 for this approach.

Roadways: Detailed Research Approach

Field personnel collected detailed data related to roadway activity in the vicinity of Dulles. These data included a count of vehicle types in fifteen-minute blocks, along with a random sampling of vehicle speeds. The actual roadway counts and speeds collected by field personnel were used as the inputs.   The default vehicle fleet mix was used for all roadways. The roadway speeds used in this approach varied by hour, but were consistently faster than the posted speed.

Mobile Lounges

Mobile Lounges: Detailed Practice Approach

The mobile lounges are unique to Dulles and therefore the detailed research information was utilized in this approach.

Mobile Lounges: Detailed Research Approach

At Dulles, mobile lounges are used to transport passengers to/from the main terminal (Figures 46, Appendix A). Based on conversations with Dulles personnel, it was determined that these lounges run on a fairly rigid schedule from day to day. Hence it was deemed most appropriate to model their movements in EDMS based on their normal daily schedule as shown in Table 1. The schedule is maintained by terminal(s) (i.e., A through D) or aircraft hard stands the lounges are serving. In EDMS, the mobile lounge routes were modeled as roadways and subsequently populated with the information provided below. The transit and urban bus mix from Mobile6.2 was used on all roadway sections that described mobile lounge pathways. The mobile lounges are designed to travel to their destination and hook up to the building so that there is no idle time associated with these unique vehicles.

Table 1 - Mobile Lounge Schedule

	A Shuttle	A-C Shuttle	A-D Shuttle	B Shuttle	C Shuttle	D Shuttle	Aircraft Trips	Totals
0800	24	16	0	24	24	22	2	112
0900	24	15	0	24	23	24	1	111
1200	24	15	0	24	24	23	1	111
1300	24	16	0	24	24	21	2	110
1600	24	16	10	24	24	23	16	137
1700	24	14	11	24	22	24	7	126

Stationary Sources

Stationary Sources: Detailed Practice Approach

Dulles airport has four natural gas fired boilers located in the Utility Building. In addition, the airport maintains several diesel-powered electric generators; however, they were not operated during the study period. Dulles personnel estimated the exhaust volume for all four natural gas boilers to be approximately 9.5 cubic meters per hour. As with the mobile lounges, the natural gas boilers at Dulles are unique to the airport and therefore EDMS input values were based on the specific data provided by Dulles personnel. This information included source diameter, gas velocity, temperature, and peak usage data. No training fires were conducted at Dulles airport during the sampling period.

Stationary Sources: Detailed Research Approach

With regard to the boilers at Dulles, the detailed research approach was identical to the detailed practice approach.

Meteorological Data

EPA's AERMET is the meteorological preprocessor to EPA's AERMOD, the dispersion algorithms used in EDMS. AERMET requires all weather data to be in a one of four formats. The data used was NOAA's TD-3280 format, which is commonly available. Fortunately for this purposes of this study, NOAA maintains a surface and upper air meteorological station in the immediate vicinity of the airport, (IAD station 93734, Lat 38 degrees, 98 minutes; longitude 77 degrees, 47 minutes). Meteorological data was obtained directly from the NOAA station at IAD for the study period. A sensitivity study was done on the weather including a complete wind angle search of the upper air data. This study showed negligible effects in the predicted output concentration from EDMS with any variation of wind angle using the upper air meteorological file.   This weather data was also compared with the TAMS data recorded during measurements for discrepancies. Since the TAMS data format could not be used directly in EDMS, it was used as a quality control check for the meteorological data. However, it is important to note that the NOAA data files are not always complete and some data is missing from the weather files.

CHAPTER 4 – RESULTS

Comparison of Measured Versus Modeled Results

The eighteen one-hour modeling periods from January 8th to January 10th were graphed for both practice detailed values as well as research detailed values and are shown in Appendix B. Overall, modeled numbers appear to have higher concentrations at receptors near stationary sources, roadways and parking lots. As a result receptors 21, 22, and 23 for the modeled data tend to have more agreement with the measured values than the other receptors. Similar trends can be seen in receptors 13 and 14 although the concentrations at these receptors are not as high. The numbers consistently showed little agreement, however, in areas where aircraft were prevalent. Four months prior to the study, the September 11th attacks drastically changed how airports operate. Due to the large amount of personnel and logistics involved in this study it was not possible to change the measurement dates. This led to fewer landing and take off cycles and could be the major factor for the low CO concentrations. The concentrations of CO for the actual measured data and both sets of modeled data are shown in Table 2, 3 and 4.

Table 2 - January 8th CO concentrations in PPM

Receptors	January 8th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
1	0.01	0.001	0	0.09	0	0	0.61	0	0	0.02	0	0	error	0	0	0.21	0.025	0.018
2	0.01	0.001	0.001	0.03	0	0	0.52	0	0	0	0	0	0	0	0	0.2	0.028	0.02
3	0.07	0.001	0.001	0.08	0	0	error	0	0	0	0	0	0.3	0	0	0.24	0.032	0.023
4	0	0.004	0.003	0.04	0	0	0.29	0	0	0	0	0	0.01	0	0	0.22	0.106	0.076
5	0.01	0.004	0.004	0.02	0	0	0.59	0	0	0.53	0	0	0	0	0	0.05	0.125	0.094
6	0.11	0.004	0.003	0.02	0	0	0	0	0	0.58	0	0	0.25	0	0	0.01	0.12	0.091
7	error	0.001	0	error	0	0	error	0	0	error	0	0	error	0	0	error	0.025	0.018
8	0.02	0.001	0	0.02	0	0	0.26	0	0	0.43	0	0	0	0	0	0	0.024	0.018
9	error	0.002	0.002	error	0	0	0	0	0	0.62	0	0	0.5	0	0	0	0.024	0.017
10	0.03	0.001	0.001	0.04	0	0	0.24	0	0	0	0	0	0	0	0	0.13	0.024	0.017
11	error	0.006	0.006	0.03	0	0	0.2	0	0	0	0	0	0	0	0	0.13	0.056	0.04
12	0	0.004	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.053	0.038
13	0	0.134	0.117	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0.507	0.364
14	0.02	0.572	0.507	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0.222
15	0	0.115	0.097	0.07	0	0	0	0	0	0	0	0	0	0	0	0.7	0.118	0.082
16	0.02	0.002	0.002	0	0	0	0	0	0	0	0	0	0.1	0	0	0.14	0.036	0.025

Receptors	January 8th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
17	0	0.006	0.005	0	0	0	error	0	0	error	0	0	0.01	0	0	0	0.085	0.06
18	0	0.005	0.004	0	0	0	0	0	0	0	0	0	0.08	0	0	0.02	0.073	0.051
19	0.04	0.001	0.001	0.06	0	0	0	0	0	0	0	0	0.12	0	0	0.13	0.023	0.016
20	0.04	0.001	0.001	0.02	0	0	0	0	0	0	0	0	0.05	0	0	0.14	0.021	0.015
21	error	0.426	0.425	error	0	0	0	0	0	0.08	0	0	0.09	0	0	0.18	8.49	0
22	0.02	0.002	0.002	0.01	0	0	0.07	0	0	0	0	0	0	0	0	0.11	11.222	0
23	0.02	0.003	0.002	0.01	0	0	0	0	0	0	0	0	0.11	0	0	0.32	2.604	0
24	0.01	0.005	0.004	0.04	0	0	0.13	0	0	0.43	0	0	0	0	0	0.03	0.135	0.101
25	0.02	0.005	0.005	0.02	0	0	0	0	0	0	0	0	0.01	0	0	0.02	0.056	0.04

*error- no recorded measurements available

Table 3 - January 9th CO concentrations in PPM

Receptors	January 9th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
1	0.33	0.004	0.001	0.11	0	0	error	0	0	0.17	0	0	0.22	0.003	0.003	0.31	0.006	0.005
2	0.28	0.005	0.001	0.05	0	0	0	0	0	0.18	0	0	0.11	0.002	0.002	0.26	0.008	0.005
3	0.1	0.006	0.001	0.1	0	0	0.21	0	0	0.21	0.001	0	0.31	0.005	0.005	0.38	0.009	0.006
4	0.33	0.018	0.003	0.08	0	0	0	0.001	0.001	0.16	0.002	0.001	0.06	0.016	0.016	0.25	0.033	0.023
5	0.59	0.02	0.004	0.59	0	0	0.01	0.002	0.001	0	0.003	0.002	0.06	0.018	0.018	0.06	0.042	0.03
6	0.13	0.019	0.003	0.48	0	0	0.31	0.001	0.001	0	0.003	0.002	0.38	0.018	0.018	0.08	0.041	0.029
7	0.05	0.005	0.001	error	0	0	0.28	0	0	0.02	0.001	0.001	0.16	0.003	0.003	0.03	0.009	0.007
8	0.32	0.004	0.001	0.33	0	0	0	0	0	0	0.001	0.001	0.01	0.003	0.003	0.01	0.009	0.007
9	0.05	0.004	0.001	0.33	0	0	0.42	0	0	error	0	0	0.03	0.003	0.003	0.25	0.006	0.004
10	0.24	0.004	0.001	0.04	0	0	0.02	0	0	0.26	0	0	0.03	0.003	0.003	0.23	0.006	0.004
11	0.18	0.009	0.005	0.1	0	0	0.04	0	0	0.05	0.001	0.001	0.03	0.008	0.008	0.12	0.016	0.011
12	0.11	0.009	0.003	0.13	0	0	0.03	0	0	0	0.001	0.001	0.11	0.007	0.007	0.03	0.015	0.01
13	0.12	0.119	0.1	0.13	0	0	0.02	0.014	0.009	0.06	0.031	0.018	0.2	0.093	0.093	0.25	0.202	0.132
14	0.13	0.072	0.232	0.13	0	0	0.02	0.007	0.004	0	0.015	0.009	0.09	0.054	0.054	0.14	0.117	0.077
15	0.13	0.026	0.111	0.11	0	0	0.06	0.002	0.001	1.08	0.003	0.002	0.1	0.019	0.019	0.67	0.038	0.024
16	0.24	0.006	0.002	0.18	0	0	0.11	0	0	0.13	0.001	0	0.21	0.005	0.005	0.13	0.01	0.006

Receptors	January 9th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
17	0.2	0.016	0.006	0.18	0	0	0.01	0.001	0.001	0	0.002	0.001	0.1	0.012	0.012	0.07	0.026	0.017
18	0.14	0.014	0.005	0.14	0	0	0.12	0.001	0	0.08	0.001	0.001	0.18	0.01	0.01	0.22	0.022	0.014
19	0.15	0.004	0.001	0.15	0	0	0.13	0	0	0.13	0	0	0.33	0.003	0.003	0.4	0.006	0.004
20	0.19	0.004	0.001	0.21	0	0	0.09	0	0	0.1	0	0	0.26	0.003	0.003	0.37	0.005	0.004
21	0.47	2.007	0.686	0.31	0	0	0.12	0.23	0.176	0.09	0.461	0.362	0.42	1.621	1.621	1.35	3.276	2.567
22	0.23	2.025	0.002	0.21	0	0	0.05	0.183	0.156	0.03	0.797	0.748	0.3	0.547	0.547	1.37	1.713	1.376
23	0.27	0.916	0.003	0.28	0	0	0.33	0.065	0.065	0.14	0.173	0.132	0.24	0.052	0.052	1.11	0.326	0.314
24	0.2	0.021	0.004	0.18	0	0	0	0.002	0.001	0	0.003	0.002	0.02	0.019	0.019	0.03	0.044	0.031
25	0.16	0.01	0.004	0.16	0	0	0.08	0	0	0.12	0.001	0.001	0.11	0.008	0.008	0.12	0.016	0.011

*error- no recorded measurements available

Table 4 January 10th CO concentrations in PPM

Receptors	January 10th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
1	error	0.002	0.001	1.44	0	0	0.31	0	0	0.05	0	0	0.22	0.007	0.007	0.31	0.015	0.014
2	0.54	0.002	0.001	1.47	0	0	error	0	0	error	0	0	0.11	0.008	0.005	0.26	0.018	0.016
3	0.83	0.003	0.002	1.13	0	0	0.02	0	0	0.07	0	0	0.31	0.01	0.009	0.38	0.021	0.02
4	0.28	0.008	0.006	0.34	0.002	0.001	0.21	0.002	0.002	0.07	0.001	0.001	0.06	0.031	0.03	0.25	0.07	0.07
5	0.23	0.009	0.006	0.1	0.002	0.001	0.36	0.003	0.003	0.41	0.002	0.002	0.06	0.035	0.031	0.06	0.087	0.085
6	0.65	0.009	0.006	0.04	0.002	0.001	0.02	0.003	0.003	0.36	0.002	0.002	0.38	0.033	0.031	0.08	0.085	0.085
7	0.04	0.002	0.002	0.02	0	0	0	0	0	0.17	0	0	0.16	0.007	0.006	0.03	0.016	0.012
8	0	0.002	0.002	0	0	0	0.11	0	0	0.23	0	0	0.01	0.007	0.007	0.01	0.016	0.015
9	error	0.002	0.001	error	0	0	0.31	0	0	0.06	0	0	0.03	0.007	0.007	0.25	0.018	0.017
10	0.02	0.002	0.001	0.06	0	0	0.26	0	0	0.04	0	0	0.03	0.007	0.007	0.23	0.017	0.017
11	0.15	0.004	0.003	0.13	0.001	0	0.05	0.001	0.001	0.05	0	0	0.03	0.017	0.016	0.12	0.042	0.041
12	0.07	0.004	0.003	0.06	0.001	0	0.02	0.001	0.001	0.1	0	0	0.11	0.016	0.015	0.03	0.04	0.04
13	0.35	0.057	0.037	0.16	0.024	0.014	0.12	0.022	0.017	0.15	0.015	0.013	0.2	0.155	0.146	0.25	0.997	0.982
14	0.25	0.033	0.022	0.12	0.012	0.007	0.1	0.01	0.008	0.15	0.007	0.007	0.09	0.094	0.091	0.14	0.258	0.256
15	0.29	0.012	0.008	0.96	0.003	0.002	0.01	0.002	0.002	0.12	0.002	0.001	0.1	0.036	0.031	0.67	0.098	0.091
16	0.5	0.003	0.002	0.47	0	0	0.06	0	0	0.19	0	0	0.21	0.011	0.009	0.13	0.026	0.026

Receptors	January 10th																	
	0800 - 0900			0900 - 1000			1200 – 1300			1300 - 1400			1600 - 1700			1700 - 1800		
	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research	Actual	Practice	Research
17	0.35	0.007	0.005	0.12	0.001	0.001	0.09	0.001	0.001	0.34	0.001	0.001	0.1	0.025	0.023	0.07	0.096	0.096
18	0.6	0.006	0.004	0.28	0.001	0.001	0.02	0.001	0.001	0.07	0.001	0.001	0.18	0.022	0.022	0.22	0.092	0.091
19	0.58	0.002	0.001	0.43	0	0	0.06	0	0	0.14	0	0	0.33	0.007	0.006	0.4	0.017	0.014
20	0.46	0.002	0.001	0.33	0	0	0.11	0	0	0.21	0	0	0.26	0.006	0.006	0.37	0.016	0.015
21	error	0.53	0.388	0.42	0.204	0.15	0.24	0.585	0.433	0.41	0.663	0.639	0.42	5.216	5.001	1.35	3.594	3.569
22	0.75	0.428	0.365	0.42	0.067	0.063	0.04	0.718	0.685	0.31	0.69	0.677	0.3	1.328	1.217	1.37	0.039	0.036
23	0.63	0.185	0.182	0.61	0.004	0.004	0.07	0.184	0.181	0.24	0.11	0.108	0.24	0.228	0.216	1.11	0.046	0.045
24	error	0.009	0.006	0.16	0.002	0.001	error	0.003	0.003	error	0.002	0.002	0.02	0.038	0.03	0.03	0.093	0.092
25	0.24	0.004	0.003	0.23	0.001	0	0	0.001	0.001	0.16	0	0	0.11	0.017	0.012	0.12	0.042	0.04

*error- no recorded measurements available

The measured values were compared to both the practice detailed model predictions and the research detailed model predictions. The discrepancies between the measured values and the EDMS predicted values were quantified by multiple percent error calculations. A value for percent error was calculated for each receptor, for each of the sampling periods of the study (Tables 5-7). An average percent error was also calculated for each of the sampling hours by averaging the percept error for all receptors in the same study hour. Tables 5, 6 and 7 show that the percent error between the modeling results and the measured values are quite variable, ranging from 0 to 100%. Percent error is calculated by taking the absolute value of the difference between the measured concentration and the modeled concentration and divide through by the value of the measured concentration. This value is then converted to a percentage by multiplying by one hundred (Equation 5).

$$\%Error = \frac{\left(X_{field} - X_{\mathrm{mod}eled}\right)}{X_{field}} * 100 \quad [5]$$

Equation 5 Percent Error

The 0% error only occurs when both the measured value is zero and the model predicted value is zero. When the model is able to predict CO concentrations other than zero, it usually over predicts. Since there are so many instances where the model predicts the total concentration to be 0 ppm at the receptor locations, there is an overall trend to under predict the CO concentrations. However there were some hours modeled in the study that demonstrated a better relationship with the measured data than others. The small concentrations recorded maybe the reason for much of the error between the measured data and modeled data. Early post 9/11 fears resulted in less air travel during the study period. The highest measured concentration during the study period was 1.47 ppm, with most values falling below 1 ppm. This is much smaller than the values expected for an airport this size. The largest difference between measured values and model predictions was 11.11 ppm, with the EDMS prediction being 11.22 ppm. This maximum value still falls far below the NAAQS for one-hour CO concentration of 35 ppm. These extremely low concentrations of carbon monoxide could account for the difficulty experienced with EDMS predictions.

Table 5 - January 8th Percent Difference

	Jan. 8 0800-0900		Jan. 8 0900-1000		Jan. 8 1200-1300		Jan. 8 1300-1400		Jan. 8 1600-1700		Jan. 8 1700-1800	
Receptors	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
1	93.97	95.32	100	100	100	100	100	100	no measured data		88.31	91.45
2	92.56	94.23	100	100	100	100	0	0	0	0	86.18	90.08
3	98.64	98.95	100	100	no measured data		0	0	100	100	86.63	90.61
4	0	100	100	100	100	100	0	0	100	100	52.03	65.4
5	56.62	64.61	100	100	100	100	100	100	0	0	150.36	88.1
6	96.25	96.94	100	100	0	0	100	100	100	100	91.7	88.97
7	no measured data		no measured data		no measured data		No measured data		no measured data		no measured data	
8	96.93	97.58	100	100	100	100	100	100	0	0	100	100
9	no measured data		no measured data		0	0	100	100	100	100	0.06	100
10	96.27	96.74	100	100	100	100	0	0	0	0	81.79	87.27
11	no measured data		100	100	100	100	0	0	0	0	56.88	69.28
12	0.4	0.36	0	0	0	0	0	0	0	0	10.99	36.67
13	13.4	11.74	100	100	0	0	0	0	0	0	100	100
14	96.5	96.06	0	0	0	0	0	0	0	0	100	100
15	11.54	9.69	100	100	0	0	0	0	0	0	83.16	88.25

Receptors	Jan. 8 0800-0900		Jan. 8 0900-1000		Jan. 8 1200-1300		Jan. 8 1300-1400		Jan. 8 1600-1700		Jan. 8 1700-1800	
	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
16	88.88	90	0	0	0	0	0	0	100	100	74.61	82.3
17	0.56	0.5	0	0	no measured data		No measured data		100	100	100	100
18	0.49	0.44	0	0	0	0	0	0	100	100	72.43	60.98
19	96.87	97.21	100	100	0	0	0	0	100	100	82.39	87.77
20	97.32	97.63	100	100	0	0	0	0	100	100	84.74	89.41
21	no measured data		no measured data		0	0	100	100	100	100	97.88	100
22	89.48	91.89	100	100	100	100	0	0	0	0	99.02	100
23	85.75	88.8	100	100	0	0	0	0	100	100	87.71	100
24	52.6	61.49	100	100	100	100	100	100	0	0	77.86	70.35
25	74.5	76.36	100	100	0	0	0	0	100	100	64.46	99.62
Avg.% Error	63.79	69.83	77.27	77.27	40.91	40.91	30.44	30.43	52.17	52.17	80.38	86.94

Table 6 - January 9th Percent Difference

	Jan. 9 0800-0900		Jan. 9 0900-1000		Jan. 9 1200-1300		Jan. 9 1300-1400		Jan. 9 1600-1700		Jan. 9 1700-1800	
Receptors	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
1	98.85	99.8	100	100	no measured data		99.78	99.86	98.64	99.19	97.95	98.53
2	98.38	99.72	100	100	100	100	99.76	99.85	98.27	98.03	97.09	97.94
3	94.45	98.99	100	100	99.9	99.94	99.75	99.85	98.53	99.14	97.61	98.34
4	94.58	98.94	100	100	100	100	98.6	99.19	73.89	85.12	86.82	90.93
5	96.66	99.39	100	100	84.96	90.29	100	100	69.51	80.72	29.98	49.75
6	85.15	97.33	100	100	99.53	99.69	100	100	95.32	97	49.26	63.35
7	90.97	98.75	No measured data		99.9	99.92	94.15	94.84	98.01	98.76	70.94	77.29
8	98.6	99.81	100	100	100	100	100	100	68.6	80.49	14.68	33.59
9	92.23	97.27	100	100	99.97	99.98	no measured data		89.65	94.09	97.5	98.36
10	98.4	99.62	100	100	99.35	99.62	99.86	99.92	89.78	94.16	97.31	98.24
11	94.79	97.36	100	100	98.9	99.36	98.17	98.89	74.15	84.97	86.41	91.04
12	91.86	96.96	100	100	98.64	99.2	100	100	93.3	96.11	48.49	66.05
13	1.24	16.71	100	100	29.15	57.04	48.52	69.75	53.59	72.29	19.32	47.04
14	44.66	78.41	100	100	65.16	79.12	100	100	40.43	64.56	16.52	44.89
15	80.11	14.84	100	100	97.13	98.34	99.68	99.81	81.5	89.25	94.35	96.37

Receptors	Jan. 9 0800-0900		Jan. 9 0900-1000		Jan. 9 1200-1300		Jan. 9 1300-1400		Jan. 9 1600-1700		Jan. 9 1700-1800	
	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
16	97.33	99.1	100	100	99.78	99.87	99.57	99.74	97.7	98.67	92.45	95.09
17	91.98	97.07	100	100	91.15	94.77	100	100	87.55	92.74	62.63	75.57
18	90.33	96.39	100	100	99.43	99.67	98.23	98.93	94.17	96.61	90.04	93.49
19	97.37	99.21	100	100	99.9	99.94	99.72	99.84	99.1	99.48	98.52	99.03
20	98.08	99.47	100	100	99.87	99.92	99.66	99.8	98.95	99.39	98.52	99.04
21	76.58	45.85	100	100	92.08	46.83	17.08	9.85	74.09	66.92	58.79	90.18
22	88.64	98.99	100	100	72.64	67.95	96.23	95.99	82.43	64.1	25.02	0.42
23	70.53	98.93	100	100	80.29	80.45	23.48	5.55	78.16	80.2	70.62	71.74
24	89.64	98.03	100	100	0	100	100	100	3.13	40.83	47.36	3.55
25	93.87	97.21	100	100	99.44	99.67	99.52	99.52	92.86	95.85	86.3	91
Avg.% Error	86.21	88.97	100	100	87.8	92.15	90.49	90.47	81.25	86.75	69.38	74.83

Table 7 - January 10th Percent Difference

	Jan. 10 0800-0900		Jan.10 0900-1000		Jan. 10 1200-1300		Jan. 10 1300-1400		Jan. 10 1600-1700		Jan. 10 1700-1800	
Receptors	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
1	no measured data		99.99	99.99	99.89	99.91	99.47	99.47	96.96	96.96	95.18	95.18
2	99.61	99.73	99.98	99.99	no measured data		no measured data		92.85	92.85	93.23	93.23
3	99.69	99.79	99.97	99.98	97.23	97.73	99.44	99.44	96.85	96.85	94.34	94.34
4	96.92	98	99.54	99.72	98.88	99.05	97.82	97.82	50.31	50.31	72.01	72.01
5	96.02	97.38	97.99	98.81	99.11	99.2	99.46	99.46	43.48	43.48	41.12	41.12
6	98.64	99.09	94.4	96.02	81.81	83.66	99.34	99.34	91.19	91.19	3.91	3.91
7	93.77	95.36	97.77	98.16	100	100	99.9	99.9	95.85	95.85	51.02	51.02
8	100	100	100	100	99.71	99.76	99.93	99.93	46.72	46.72	26.59	26.59
9	no measured data		no measured data		99.9	99.92	99.69	99.69	77.8	77.8	92.98	92.98
10	88.85	92.76	99.7	99.82	99.89	99.91	99.53	99.53	78.04	78.04	92.45	92.45
11	97.13	98.16	99.56	99.74	98.33	98.66	99.1	99.1	48.24	48.24	65.16	65.16
12	93.9	96.09	99.07	99.45	95.73	96.6	99.59	99.59	85.75	85.75	24.95	24.95
13	83.39	89.27	84.49	90.7	81.04	85.53	89.59	89.59	22.37	22.37	74.99	74.99
14	86.48	91.2	89.79	93.84	89.24	91.84	94.91	94.91	2.45	2.45	83.14	83.14
15	95.92	97.3	99.71	99.83	68.03	76.3	98.33	98.33	64.54	64.54	85.44	85.44

	Jan. 10 8-9		Jan. 10 9-10		Jan. 10 12-1		Jan. 10 1-2		Jan. 10 4-5		Jan. 10 5-6	
Receptors	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research	Practice	Research
16	99.44	99.63	99.93	99.96	99.23	99.41	99.85	99.85	94.95	94.95	79.82	79.82
17	97.92	98.65	98.86	99.31	98.37	98.72	99.72	99.72	75	75	34.05	34.05
18	98.99	99.34	99.65	99.79	93.56	94.99	98.92	98.92	88.01	88.01	58.26	58.26
19	99.71	99.81	99.96	99.98	99.51	99.62	99.87	99.87	97.93	97.93	95.75	95.75
20	99.66	99.77	99.95	99.97	99.75	99.81	99.92	99.92	97.56	97.56	95.72	95.72
21	no measured data		50.74	63.78	59.58	45.47	63.62	63.62	100	100	62.54	62.54
22	42.5	50.98	83.86	84.88	94.8	94.55	55.66	55.66	100	100	97.13	97.13
23	70.42	70.84	99.28	99.35	63.58	62.91	53.63	53.63	4.72	4.72	95.86	95.86
24	no measured data		98.79	99.25	no measured data		no measured data		71.19	71.19	65.57	65.57
25	98.15	98.81	99.74	99.85	100	100	99.71	99.71	84.98	84.98	64.92	64.92
Avg.% Error	88.05	89.63	95.53	96.76	92.05	92.33	93.35	93.347	72.31	72.31	69.85	69.85

CHAPTER 5 – CONCLUSIONS

Based on the analysis conducted in this study it appears that the data collected were inadequate to properly assess the ability of EDMS to predict airport CO concentration. There were some hours in the study that demonstrated a better correlation with the measured data and the model predicted data than others. Two such examples are shown in Figures 14 & 15. Figure 14 and Figure 15 show the model predicting peak concentrations in the correct receptor locations but above the actual concentrations. The hourly, valet and daily parking areas are located north of the main terminal, encircled by receptors 21, 22, and 23. Located near receptors 13, 14 and 15 is ground support equipment staging areas as well as the economy parking areas. It is also important to note that all parking areas are located near roadways. The percent error for these two scenarios is still high but they show a possible correlation between the modeling results and the actual values most likely due to mobile sources.

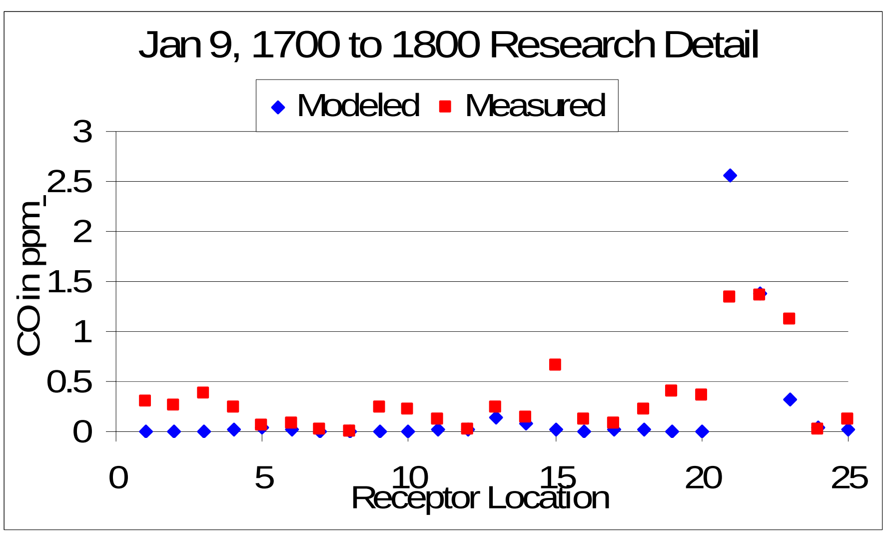

Figure 14 Measured Versus Modeled Research Detail: January 9, 2002 5pm to 6pm

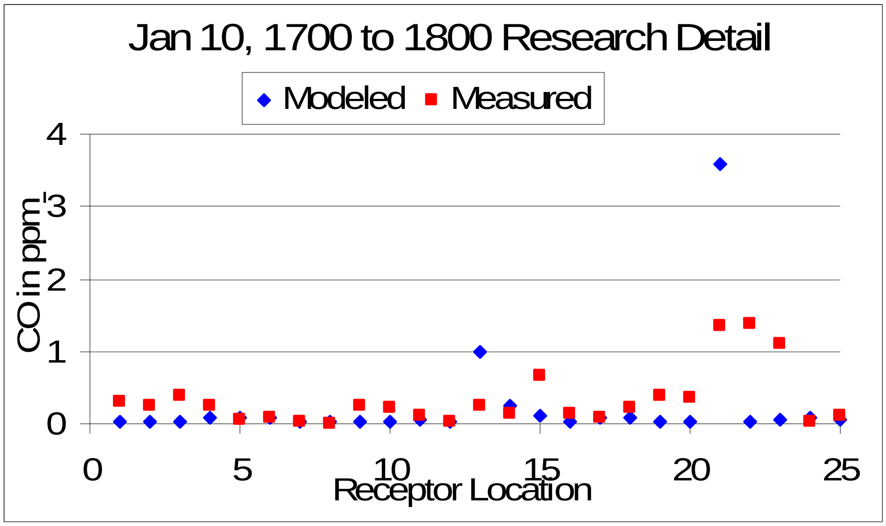

Figure 15 Measured Versus Modeled Research Detail: January 10, 2002 5pm to 6pm

Many of the modeling scenarios reported zero concentrations for all receptors. This was not representative of the actual values and an example of this is shown in Figure 16. Another interesting output of the modeling can be seen in Figure 17. An area of unusually high concentration in the modeled data dominates the graph because the receptors in this area have a much higher concentration than any of the actual receptor values. However, if these three receptors of very high concentrations are excluded from the graph the correlation seems to improve. Figure 18 shows the same graph as Figure 17, excluding receptors 21, 22 and 23. The concentration plots for each time period for both modeling methods compared with measured values are located in Appendix B Figures 51-121.

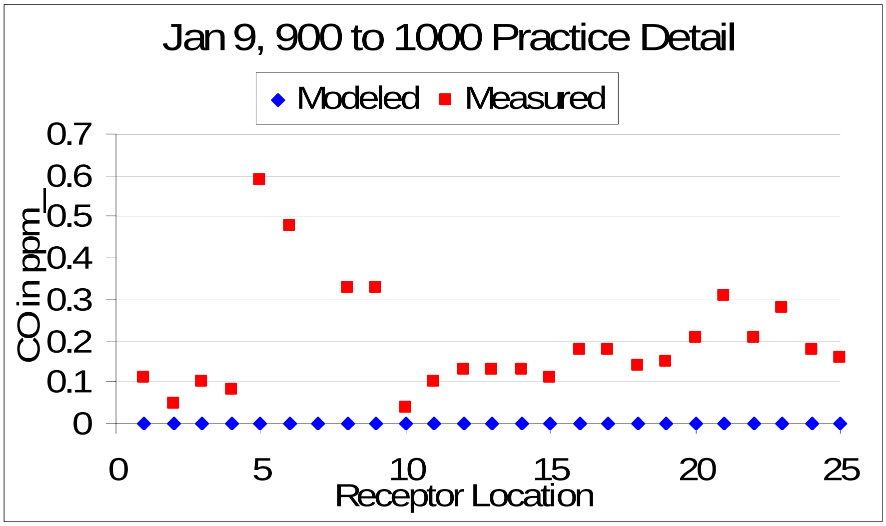

Figure 16 Measured Versus Modeled Practice Detail: January 9, 2002 9am to 10am

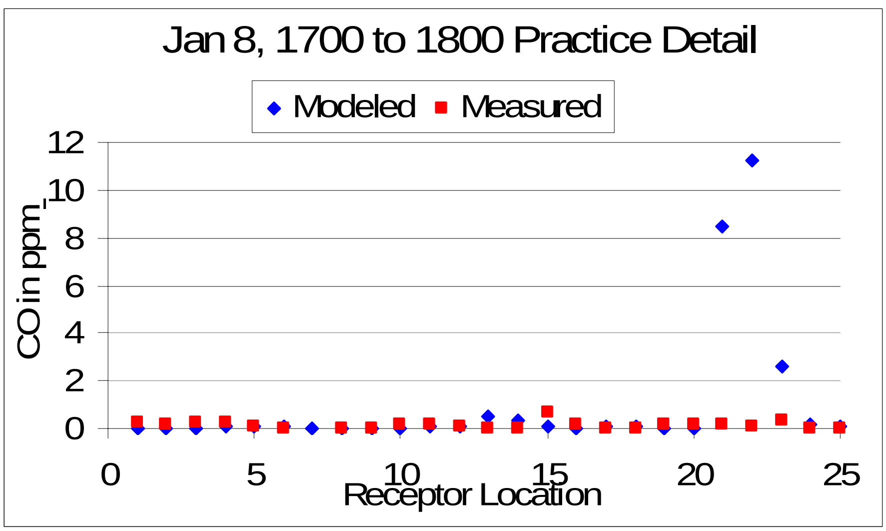

Figure 17 Measured Versus Modeled Practice Detail: January 8, 2002 5pm to 6pm

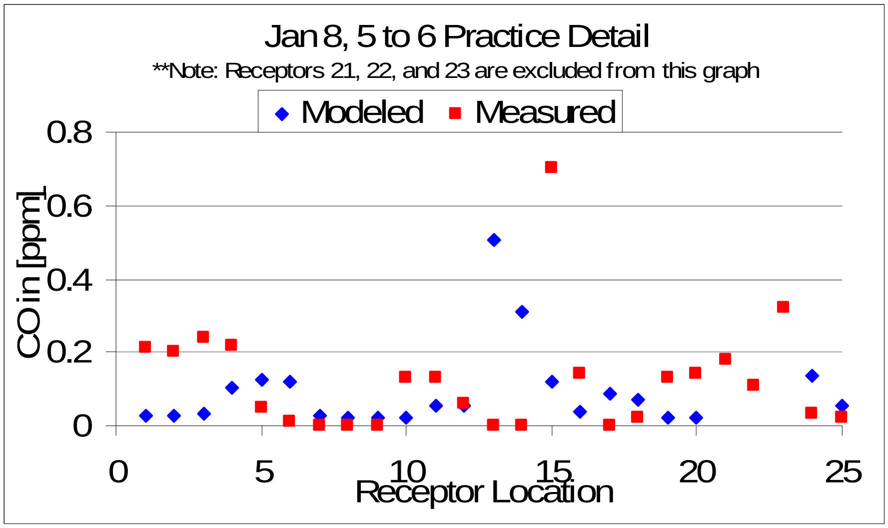

Figure 18 Measured Versus Modeled Practice Detail: January 8, 2002 5pm to 6pm

The resulting concentrations from the EDMS model were analyzed using a statistical least squares approach. The individual regression trends are shown for all sampling periods in Figures 123-158 in Appendix B. The graphs show the equation for the best-fit trend line and the value of the correlation coefficient for each hour of sampling. Linear regression was applied as the most common graphically approach for comparing modeled versus measured. However in can be seen from Figure 18 that much of the correlation appeared to be due to the high concentrations predicted a receptor 21, 22, and 23.

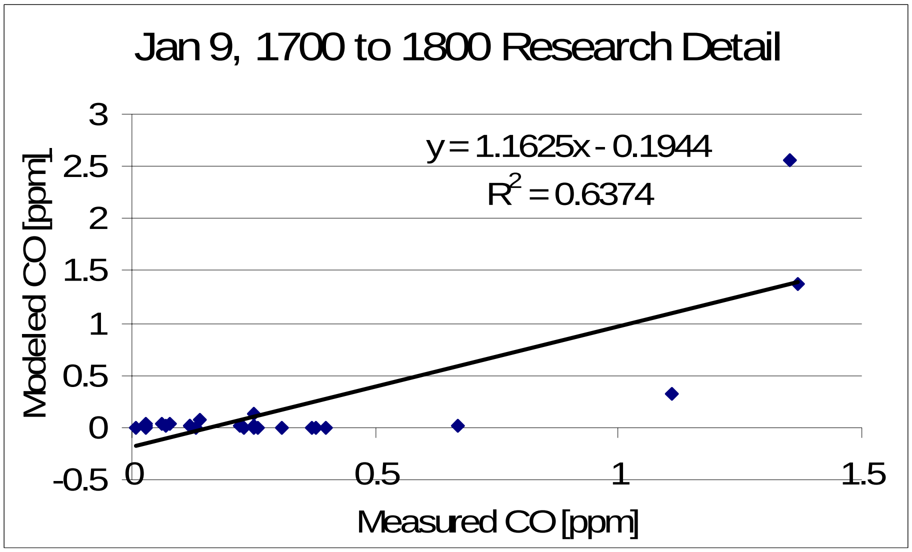

Figure 19 January 9, 5 to 6 Research Detailed Modeling Linear Regression

The sample size in this study was less than 30, so a paired two tailed student t-test was performed. This statistical test used a critical value of 0.05 as the rejection region to test the hypothesis that the measured values within the confidence interval. The results were split down the middle for both the research detail and the practice detail. For the 6 hours of sampling each day it showed that 3 of the hours fell with in the confidence interval and 3 did not. The hour of 900-1000 consistently fell outside of the confidence interval for all 3 days of the study and both methods of modeling. The results of the student t-test are presented in Table 8 and the critical values from the student t-test are presented in Appendix C in Tables 11-13. The rejection periods are highlighted in Table 8 and it appears that there is slightly better agreement between modeled and measured results in the afternoon.

Table 8 Results of Student t-test

Date	Time	Measured vs. Practice	Measured vs. Research
1/8/2002	800 - 900	accept	accept
	0901 - 1001	reject	reject
	1200 - 1300	reject	reject
	1301 - 1401	accept	accept
	1600 - 1700	reject	reject
	1701 - 1800	accept	accept
1/9/2002	800 - 900	reject	reject
	0901 - 1001	reject	reject
	1200 - 1300	reject	reject
	1301 - 1401	accept	accept
	1600 - 1700	accept	accept
	1701 - 1800	accept	accept
1/10/2002	800 - 900	reject	reject
	0901 - 1001	reject	reject
	1200 - 1300	accept	accept
	1301 - 1401	reject	reject
	1600 - 1700	accept	accept
	1701 - 1800	accept	accept

The low CO concentrations may be responsible for some of the difficulty in the modeling process. Maximum one hour concentrations for each of the sampling periods with their corresponding receptor locations were examined for possible correlation. The highest hourly concentration for each scenario was plotted in Figure 20. This Figure shows that the peak CO concentration occurs in the afternoon, perhaps explaining why there is better correlation toward the end of the sampling day. Both of the modeling scenarios seem to over predict the peaks, but predicted no concentration when smaller measurement concentrations are seen.

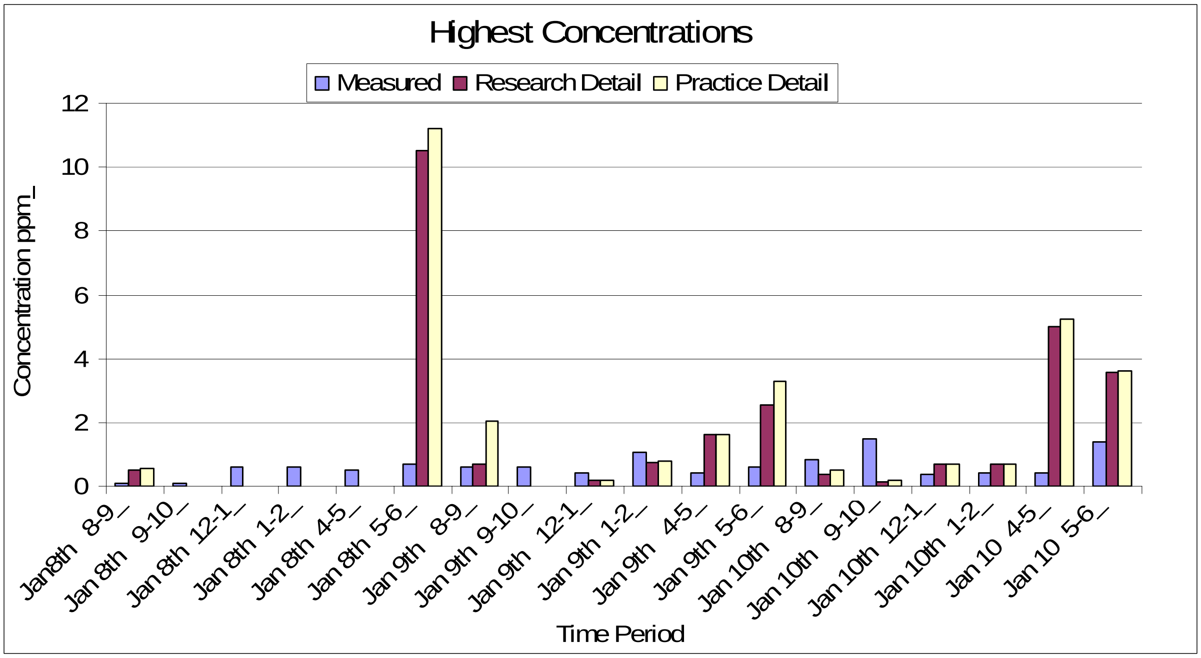

Figure 20 Highest Concentration by Hour

Figure 21 is a graph of the highest concentrations by receptor. The modeling results predict the highest concentration at receptors 21 and 22 most often. It is important to note that receptor zero is used when all concentrations predicted in a given hour were zero. There are 3 locations where the measured values correspond well with the modeled values, these all occur at receptors 21 and 22. The only other area of the graph that seems to show any correlation is the model predictions at receptor 14 which seem to be somewhat similar to the measured values at receptor 15. These receptors are in the same general vicinity near parking areas and seem to have similar concentrations.

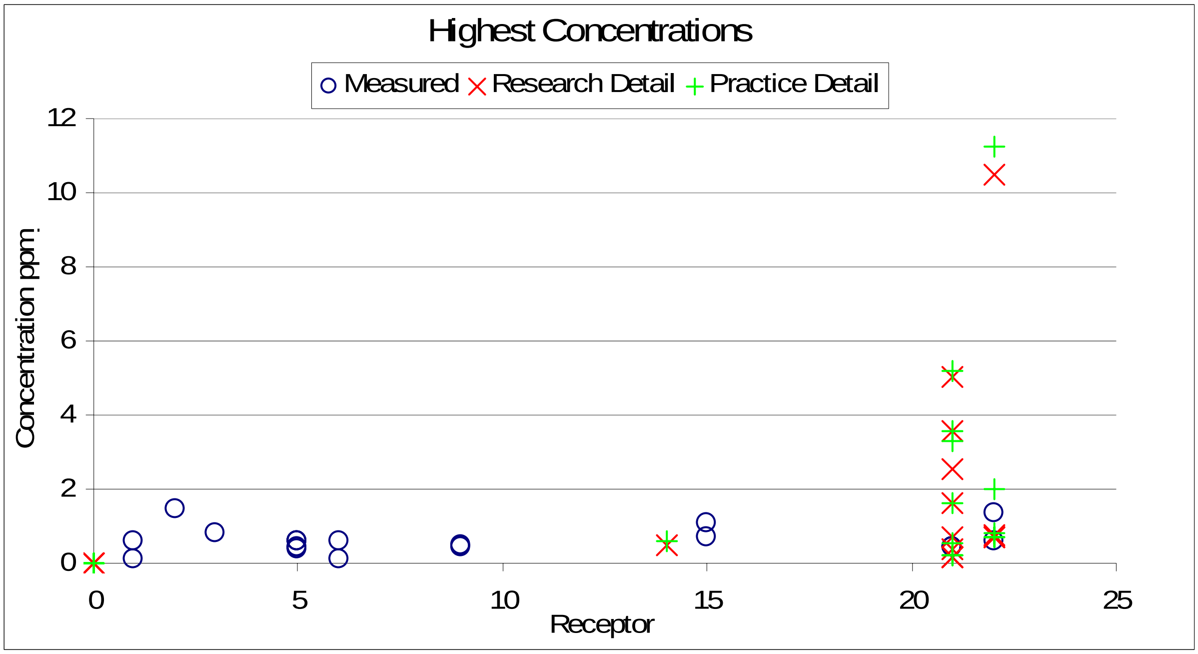

Figure 21 Highest Concentrations by Receptor

Table 9 is an example of an EDMS annual emissions inventory from one of the sample periods. During the research detailed modeling the largest CO contributing source is consistently roadways.

Table 9 January 8th 800-900 Research Detail Emissions Inventory

	January 8th 800-900 Research Detail							
Category	**CO**	**THC**	**NMHC**	**VOC**	**NOx**	**SOx**	**PM-10**	**PM-25**
Aircraft	173.392	26.293	26.293	28.228	474.204	35.411	0.000	0.000
GSE/APU	447.909	25.037	23.266	24.418	92.354	12.874	6.230	6.035
Roadways	1625.353	93.396	88.193	87.129	137.572	3.584	3.358	2.449
Parking Facilities	156.070	11.696	10.962	10.842	12.76	0.324	0.285	0.203
Stationary Sources	2.944	4.862	4.862	4.862	11.773	0.050	0.252	0.252
Total	2415.847	162.542	154.711	156.613	729.597	52.243	10.125	8.939

The overall magnitude of sources in the practice detailed modeling is dominated by the ground support equipment (Table 10). This is primarily due to the use of the default ground support equipment for all aircraft in this approach.

Table 10 January 8th 800-900 Practice Detailed Emissions Inventory

	January 8th 800-900 Practice Detail							
Category	**CO**	**THC**	**NMHC**	**VOC**	**NOx**	**SOx**	**PM-10**	**PM-25**
Aircraft	173.392	26.293	26.293	28.228	474.204	35.411	0	0
GSE/APU	3442.018	137.105	124.133	128.983	184.385	17.075	5.53	5.317
Roadways	1533.392	91.903	86.727	85.609	130.129	3.584	3.349	2.438
Parking Facilities	46.182	4.293	4.034	3.994	3.246	0.081	0.075	0.042
Stationary Sources	2.944	4.862	4.862	4.862	11.773	0.05	0.252	0.252
Total	5197.928	264.456	246.049	251.676	803.737	56.201	9.206	8.049

The results from the sensitivity study showed the number of passenger vehicles had a large impact on CO concentrations. When the volume of traffic was increased in the parking areas the predicted CO concentrations increased as well. This increase was noticeable but not significant. This is perhaps because mobile sources on roadways are of more concern than mobile sources in parking area. Wind direction was thought to be an important parameter for dispersion analysis; however varying wind angles alone did not yield a better correlation between the EDMS predicted concentrations and the measured values. However, upon further investigation of the highest model predicted values, it appears that the wind came directly out of the north for this hour of the study. It appears as though an upwind source could have led to increased CO concentrations at receptor 22 during this hour. The base wind height was varied 5 meters above and below the default base wind height of 10 meters. The concentrations increased slightly as the base wind height increased. This increase was most likely due to the decreased dispersion effect of the wind on sources closer to the ground, such as automobiles. When the wind height was varied along with the wind angle, there were some instances where the correlation improved. However, this was not consistent through out the different hours and days of the study. In fact many times the variations only changed the magnitude of the difference between the measured and modeled values.

This study of EDMS has yielded dramatic results. The measured concentrations were overall higher than the model's predictions. This trend toward under prediction occurs because the model predicts no concentration at all receptors for 5 hours of the study. There were occasional spikes where the model greatly over predicted the actual measured CO concentrations. These higher predictions occurred at receptor locations 13, 14, and 15 as well as 21, 22, and 23, which were all located near parking areas and roadways. The highest concentrations located at receptors 21 and 22 were most likely due to the stationary sources and roadways. Both natural gas boilers were located near these receptors. The fact that there was limited correlation between the actual measurements and the EDMS modeled prediction may be surprising. It may not be the desired outcome, but it is a very important finding. Since EDMS has been in use for two decades assumptions have been made regarding its accuracy. The emission factors used in EDMS are well documented leaving one to believe that the dispersion abilities of EDMS maybe limited by its primary processor, AERMOD.

In recent years there have been many changes, not only in airport operations, but equipment and technology as well. Cars and planes have benefited from public awareness of air pollution and improvements in design and technology have produced lower emission engines. There is an increase in the amount of automobile traffic from passengers, which may be the largest source of CO emissions at airports. Although the number of passenger vehicles and ground support vehicles has increased, they have also gotten cleaner. The greater accuracy of the model near parking lots and roadways could be due to mobile sources being the largest contributor of CO emissions. The low concentrations of CO at all measured locations could be indicative of the factor that CO may no longer be a pollutant of concern at airports. Even though there has been much progress in the ability of models to represent real world situations, it is important to remember not only their limitations but also why they are needed. Measurements will always prove more accurate than modeling but they will come at a cost. Not only is measuring expensive, but it is impossible to measure emission sources before they have been constructed. Modeling provides a more affordable, conservative, reproducible way of evaluating sources of potential problems (Cooper and Alley 2002).

In summary the major findings from this analysis are:

- Low CO concentrations resulted in error in the analysis.
- There are small differences in practice detailed modeling and research detailed modeling, but research detailed modeling resulted in lower CO concentrations.
- CO from airports has dropped significantly and CO seems to no longer be a concern at airports.
- Wind from a single angle may be an over simplification. A prognostic wind model could be beneficial in characterizing wind patterns.
- AERMOD has only been validated for point sources and therefore may not be accurately accounting for all airport sources.

- Any future work with this data should focus on the nine sampling hours that fell within the accepted confidence interval.

CHAPTER 6 – RECOMMENDATIONS

The following near and long-term recommendations should be considered to further account for the poor agreement between EDMS Version 4.21 modeled values and field measurements. However, it should be noted that all CO concentration measured and modeled in this study were low and fell below the NAAQS for CO.

Perform additional sensitivity studies

Sensitivity analysis is a tool for evaluating the impact on a process to key operating and design variables. The results presented in this thesis were derived from modeling data using EDMS Version 4.21. Systematic and technically justifiable changes to various EDMS process variables may help explain the differences observed in this study between measured and modeled values. Since EDMS is constantly evolving, changing, and improving, these sensitivity studies will provide a better understanding of how AERMOD dispersion algorithms should be applied for aviation sources within EDMS, and hence an improved and more technically justified model will result. For example, based on guidance from the AERMIC, EDMS uses AERMOD algorithms to model aircraft as area sources within EDMS where it may be more appropriate to model aircraft as volume sources, a feature that can be enhanced in the next version release of EDMS. Roadways seemed to be the major source of CO so additional sensitivity studies with traffic variations may prove useful.

Develop software to determine proper aircraft runway assignments

Since many assumptions had to be made based on guidance from Dulles personnel, a way to insure the correctness of these inputs could prove to be invaluable. Software could be developed to determine exact runway and taxiway usage for individual flights. This, in turn, would allow for runways, taxiways and even gates to be properly loaded in EDMS. This may lead to more accurate CO predicted concentrations near runways and taxiways.

Model a different pollutant

A study for nitrogen oxides may produce greater volumes of emissions and could be easier to compare and model than CO. Carbon monoxide has shown a decreasing trend for many years as background concentrations have greatly diminished (Shiller, Pezda, and Douglass 1982). Other pollutants that appear in larger concentrations at airports such as NO_x, toxics and PM should be considered if an additional study was to be performed. Many of the advances expected in the next version of EDMS pertain to the particulate matter concentration and nitrogen oxides. This enhancement may greatly improve the comparison of modeled versus measured data. The high combustion temperature of aircraft engines leads to increased NO_x emissions. This pollutant is recommended for future work because it is a precursor to ozone and is still a major concern at airports. It can be seen from the emissions inventory table that NO_x is the pollutant of greatest concern emitted from aircraft. The mass of NO_x predicted from aircraft in the emissions inventory is more than twice the mass of any other pollutant predicted from aircraft.

Conduct measurements with a tracer gas

Because CO may not be prevalent enough to accurately access dispersion characteristics in EDMS, an alternative would be to perform a focused and controlled study of dispersion from a single aircraft. Such a study could be performed by injecting a tracer gas, such as sulfur hexaflouride (SF6) directly into the fuel stream of a test aircraft. As one possibility, the National Aeronautics and Space Administration (NASA) have test aircraft available that could potentially be used for this type of investigation.

APPENDIX A – ILLUSTRATIONS

Figure 22 Sampler Unit Positioned to Capture Takeoff Ground Roll

Figure 23 Sampler Unit Positioned to Capture Landing

Figure 24 Sampler Positioned Near Landside Roadway

Figure 25 Reference Inlet and Co-Located Air Sampler

Figure 26 Trailer which Served as Base of Operations

Figure 27 Pole-Mounted Installation

Figure 28 Tripod-Mounted Installation

Figure 29 Fence-Mounted Installation

Figure 30 Light-Post Mounted Installation

Figure 31 Minivol Air Sample Unit

Figure 32 NDIR Analyzer

EDMS Validation Study

Aircraft/Gate Activity Log

Name: ______________________ Date: ______________ Page __ of __

Arrival Runway (E/W)	Arrival Taxiway Name	Arrival Taxi+Queue Time Duration (min, sec)	Gate #	Gate Block IN Time (e.g., 9:45:07 AM)	Aircraft Tail #	Aircraft Type	Airline	GSE/APU Activity		Gate Block OUT Time (e.g. 10:54:34 AM)	Departure Taxi+Queue Time Duration (min, sec)	Departure Taxiway Name	Departure Runway (E/W)
								Name	Time Duration (min, sec)				

Figure 33 Airside Activity Log

EDMS Validation Study

Vehicular Traffic Log

Name: ________________ Date: ____________ Site ID: __________ Page __ of __

Site Location: ____________________________ Traffic Direction: ____________________________

Start time	Stop time	Vehicle Types						Speed (mph)
		Compact Auto	Large Auto	Medium Truck	Heavy Truck	Bus	Motorcycle	

Figure 34 Landside Activity Log

Figure 35 TAMS System at Site 2

Figure 36 RM Young System at Site 13

Figure 37 DGPS Base Station

Figure 38 DGPS Rover

Figure 39 Dulles Ramp Tower

Figure 40 Rudder Road Overpass

Figure 41 Evacuation of the Tedlar Bag

Figure 42 Analysis of Bag Sample Using NDIR

Figure 43 Retrieving and Deployment of Sample Canisters

Figure 44 Typical View of Terminal Area for Ramp Tower

Figure 45 Dulles Plane Mate

Figure 46 Dulles Mobile Lounge

Figure 47 Dulles Baggage Carriers

Figure 48 Dulles Catering Truck

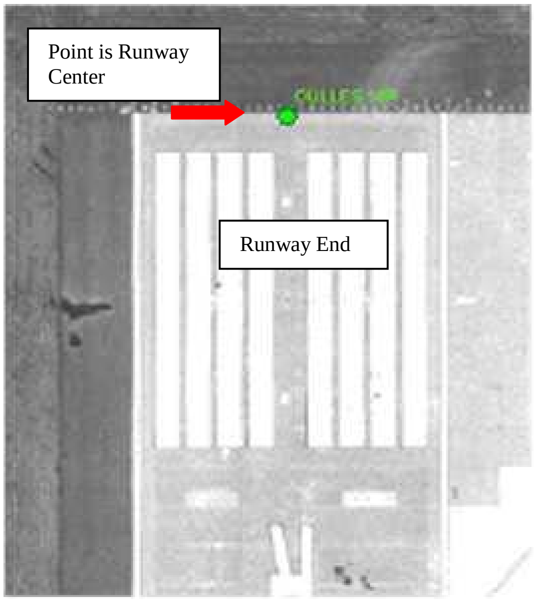

Figure 49 Comparison of Runway Image with GIS Point

Figure 50 Overlay of dGPS Data and Image File

APPENDIX B – GRAPHS OF MEASURED VERSUS MODELED DATA

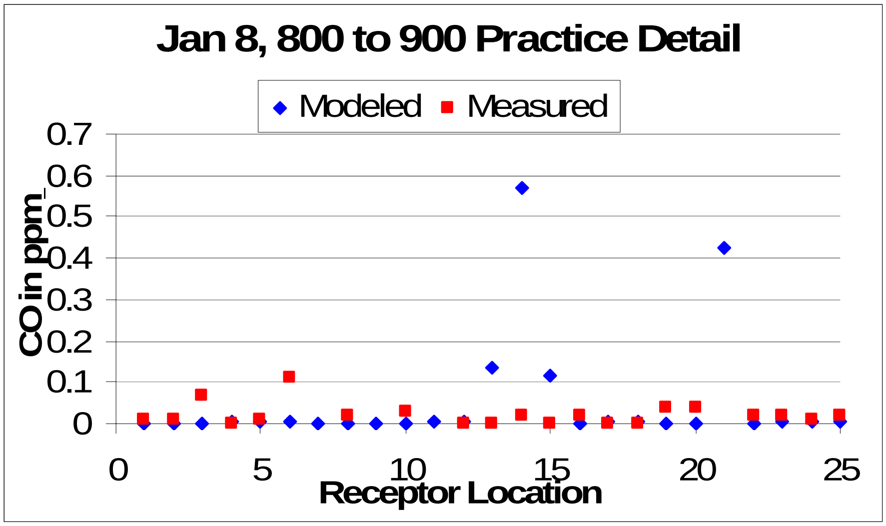

Figure 51 Measured Versus Modeled Practice Detail: January 8, 2002 8am to 9am

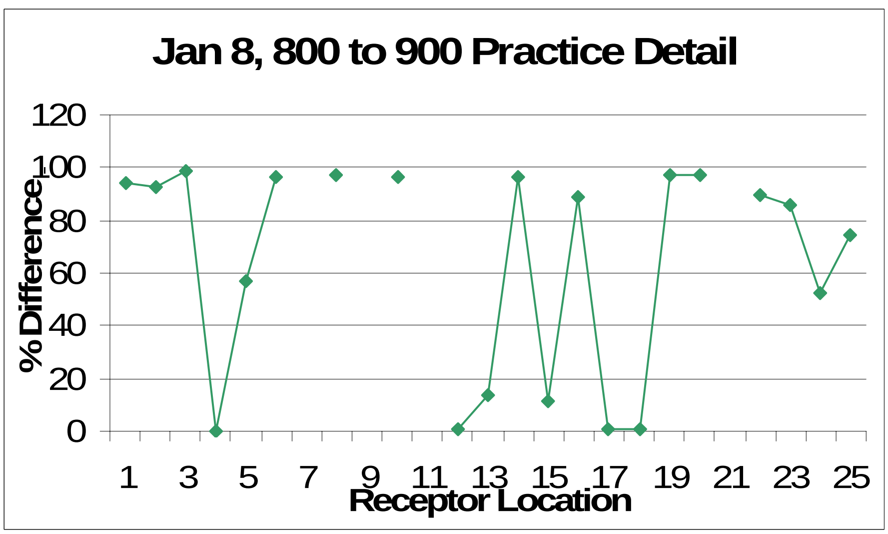

Figure 52 Measured vs. Modeled Practice Detail % Difference: 1-8-2002 8am to 9am

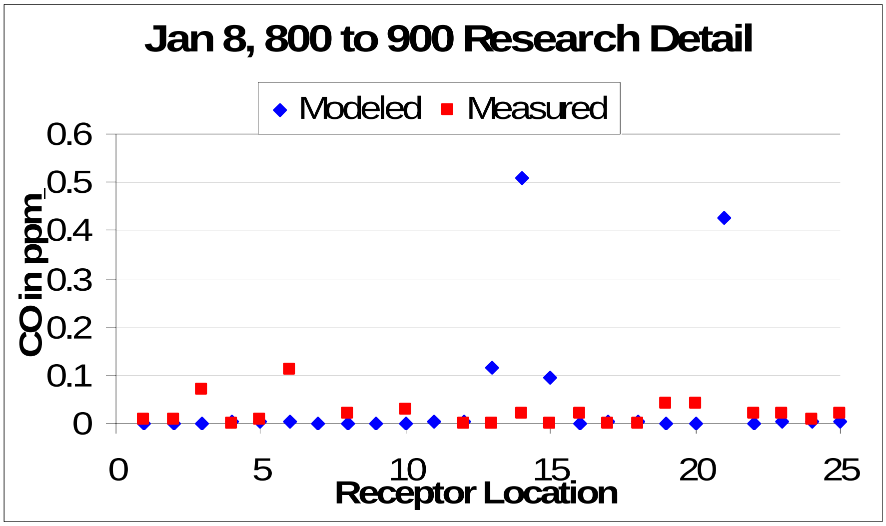

Figure 53 Measured Versus Modeled Research Detail: January 8, 2002 8am to 9am

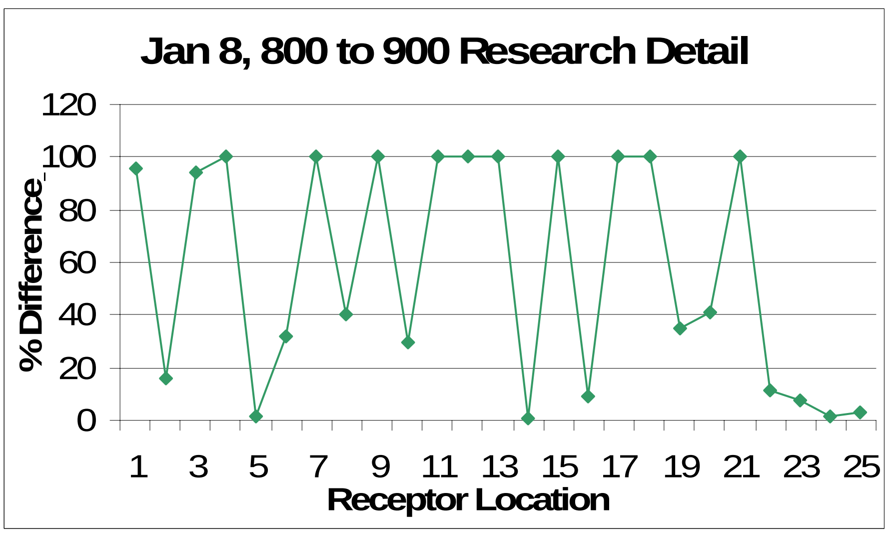

Figure 54 Measured vs. Modeled Research Detail: % Difference: 1-8-2002 8am to 9am

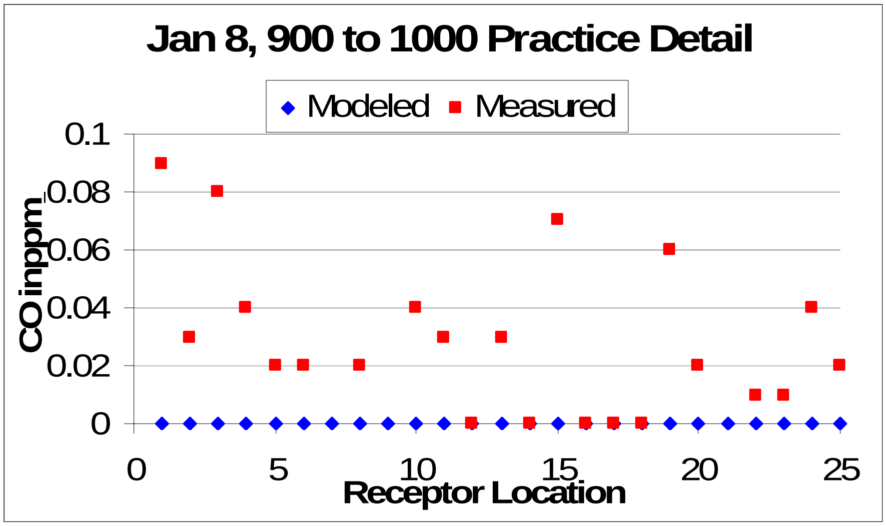

Figure 55 Measured Versus Modeled Practice Detail: January 8, 2002 9am to 10am

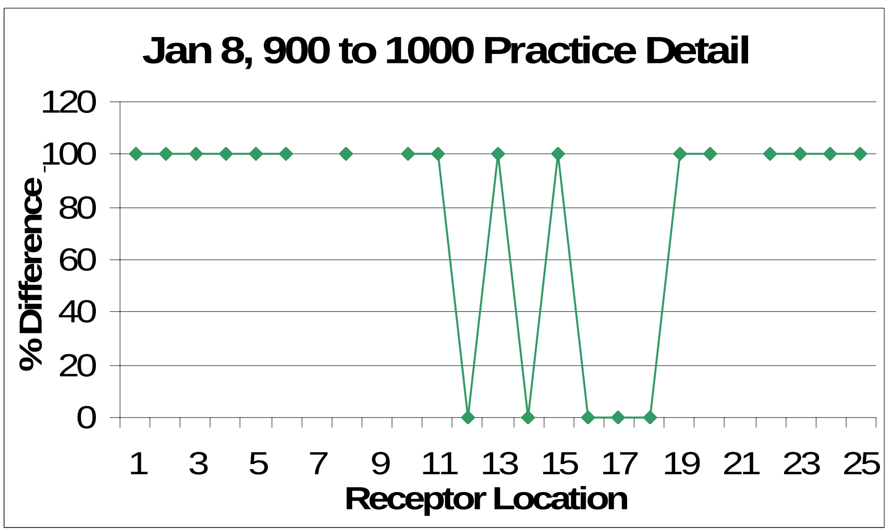

Figure 56 Measured vs. Modeled Practice Detail % Difference: 1-8-2002 9am to10am

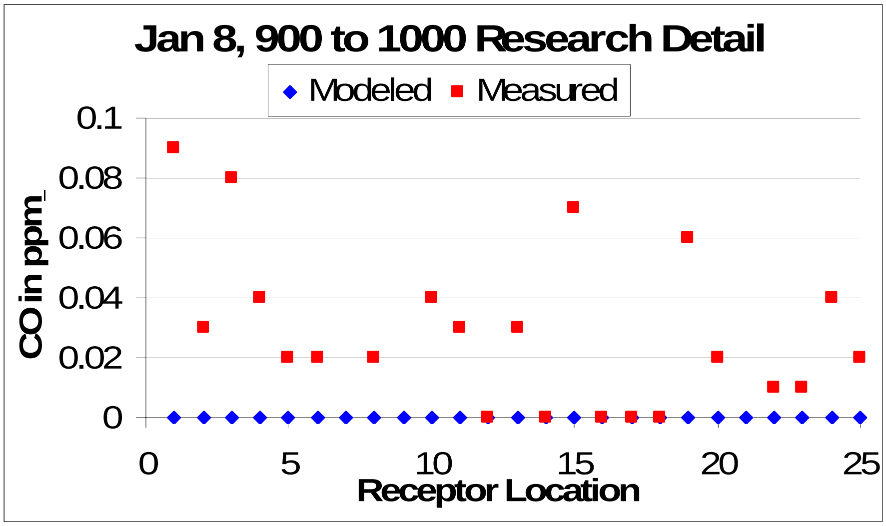

Figure 57 Measured Versus Modeled Research Detail: January 8, 2002 9am to 10am

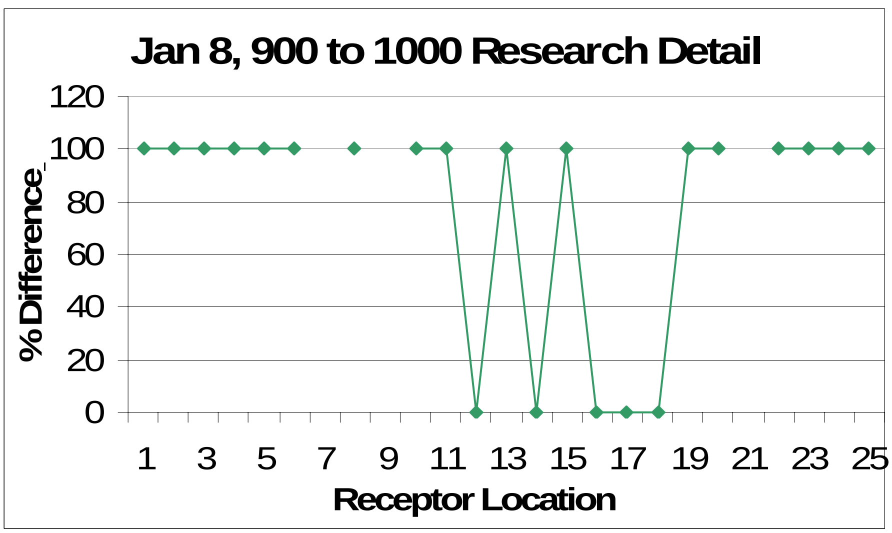

Figure 58 Measured vs. Modeled Research Detail: % Difference: 1-8-2002 9am to 10am

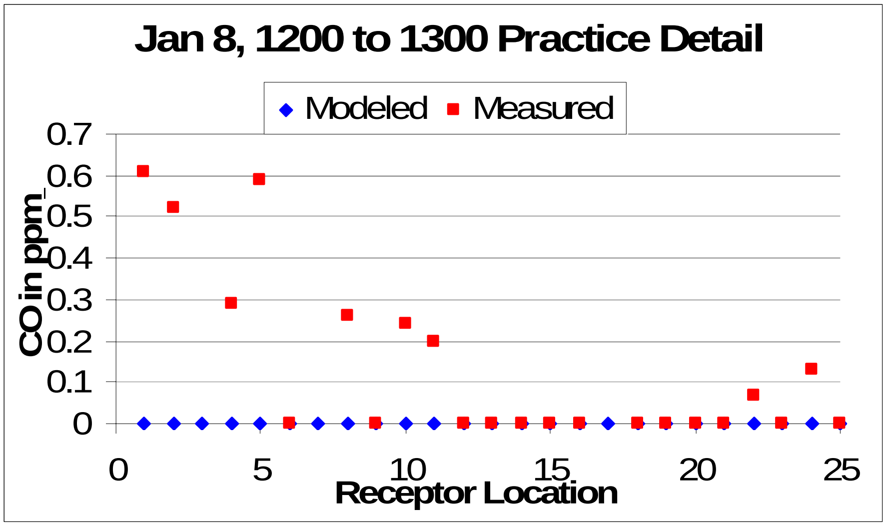

Figure 59 Measured Versus Modeled Practice Detail: January 8, 2002 12pm to 1pm

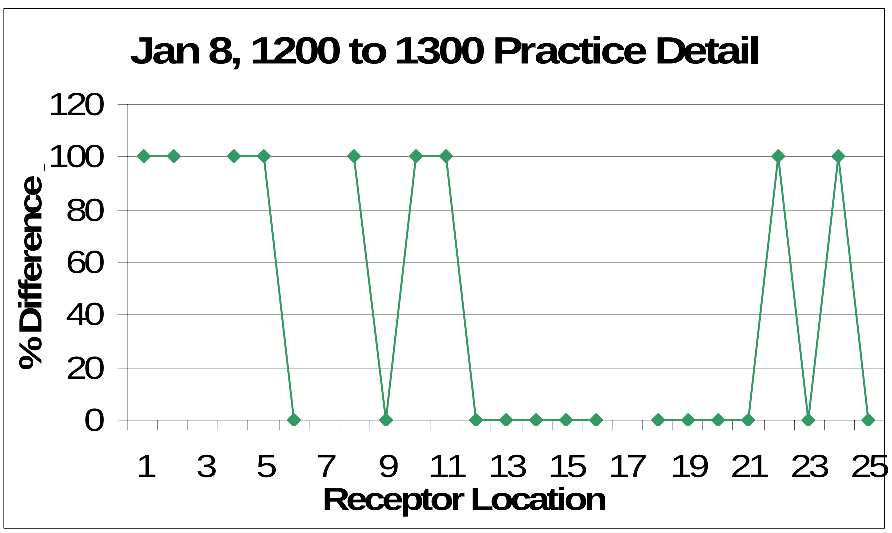

Figure 60 Measured vs. Modeled Practice Detail % Difference: 1-8-2002 12pm to 1pm

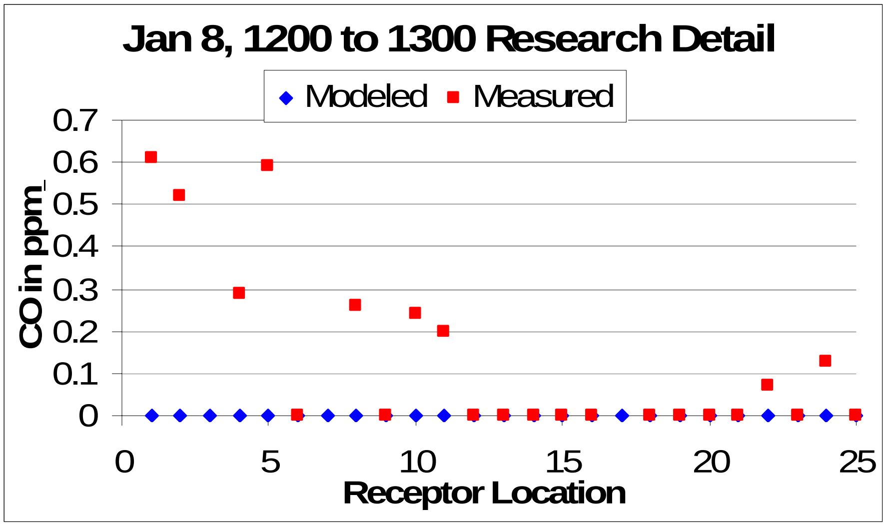

Figure 61 Measured Versus Modeled Research Detail: January 8, 2002 12pm to 1pm

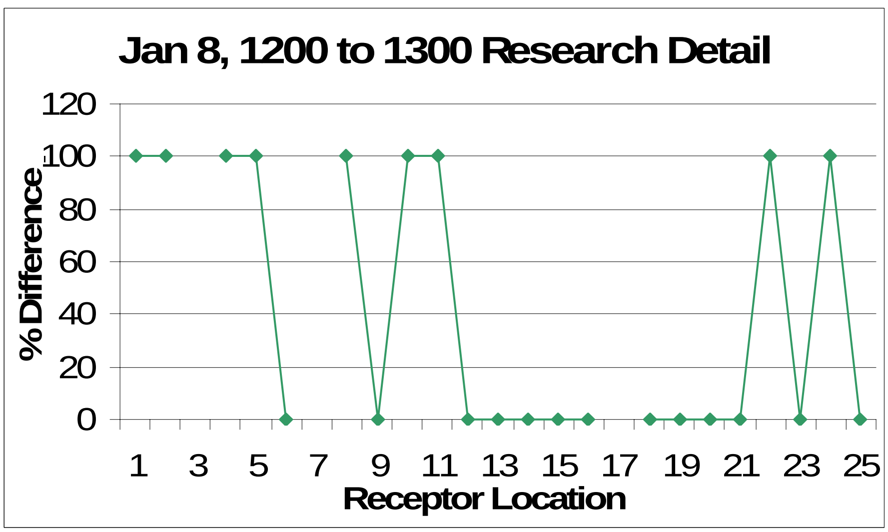

Figure 62 Measured vs. Modeled Research Practice Detail: % Difference: 1-8-2002 12 to 1

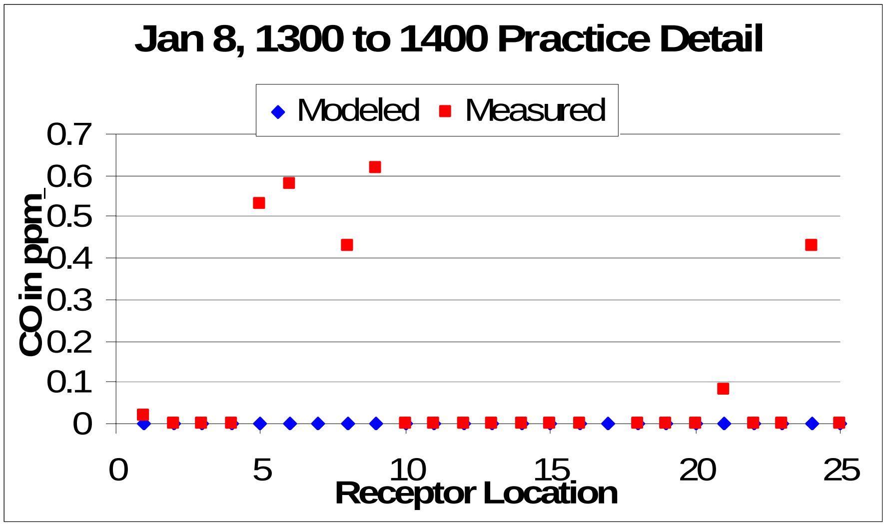

Figure 63 Measured Versus Modeled Practice Detail: January 8, 2002 1pm to 2pm

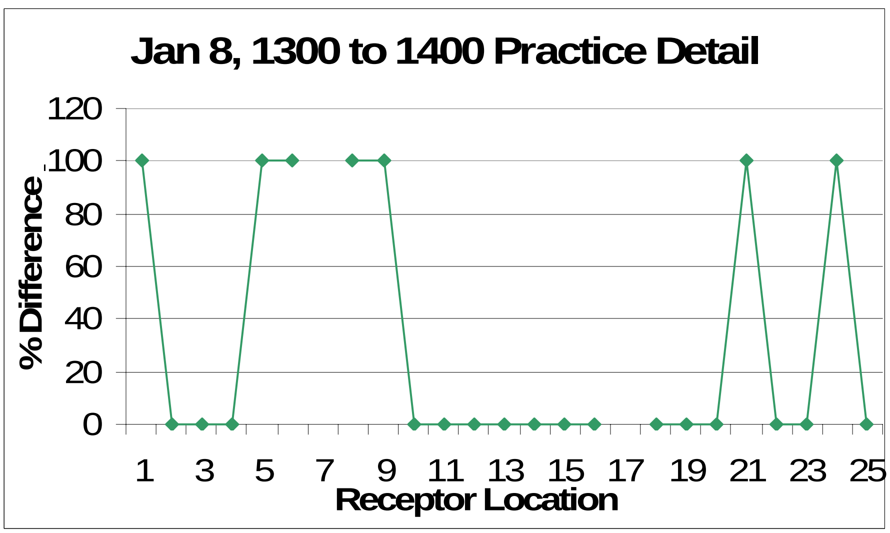

Figure 64 Measured vs. Modeled Practice Detail % Difference: 1-8-2002 1pm to 2pm

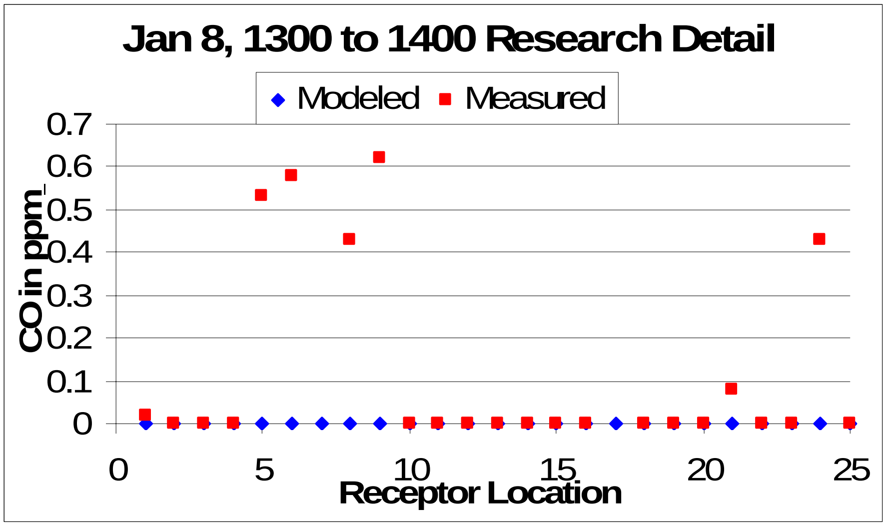

Figure 65 Measured Versus Modeled Research Detail: January 8, 2002 1pm to 2pm

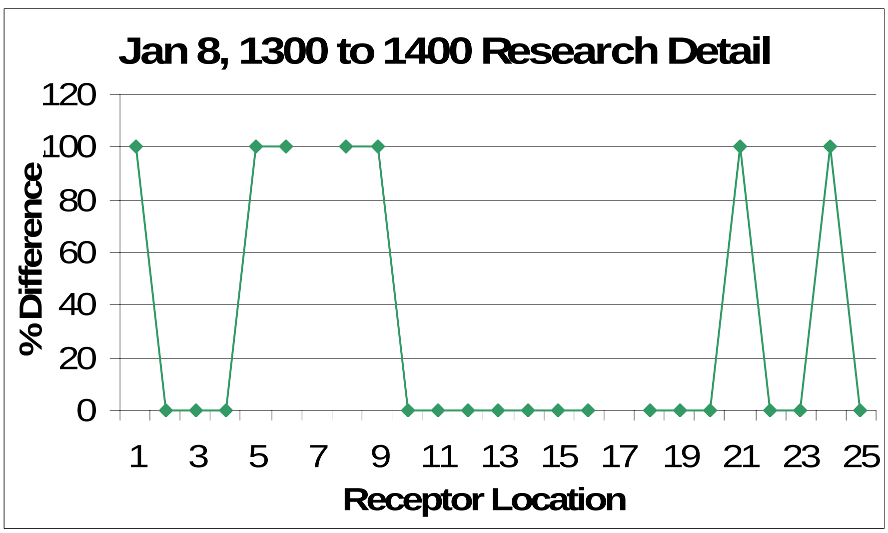

Figure 66 Measured vs. Modeled Research Detail: % Difference: 1-8-2002 1pm to 2pm

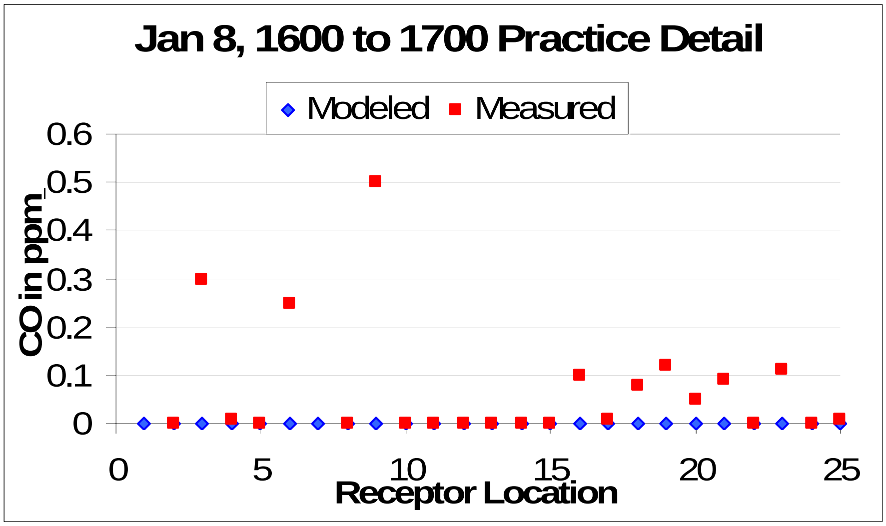

Figure 67 Measured Versus Modeled Practice Detail: January 8, 2002 4pm to 5pm

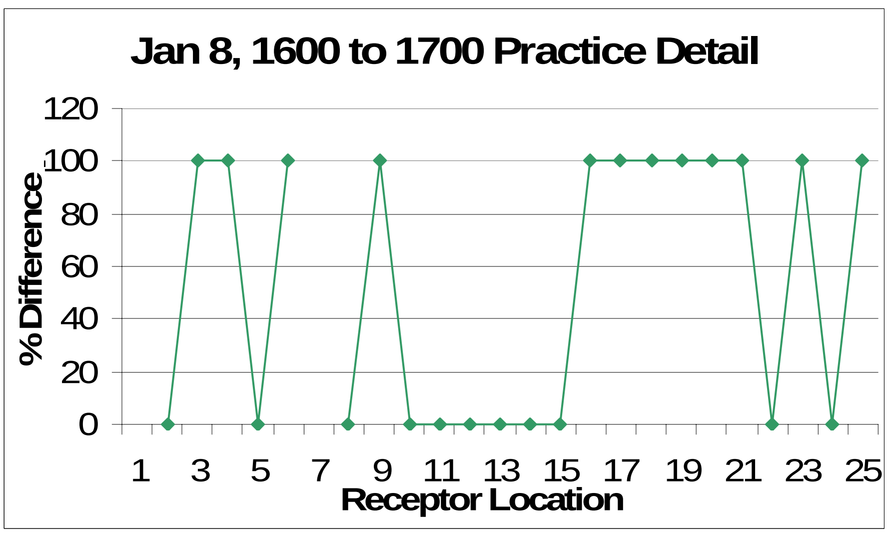

Figure 68 Measured vs. Modeled Practice Detail % Difference: 1-8-2002 4pm to 5pm

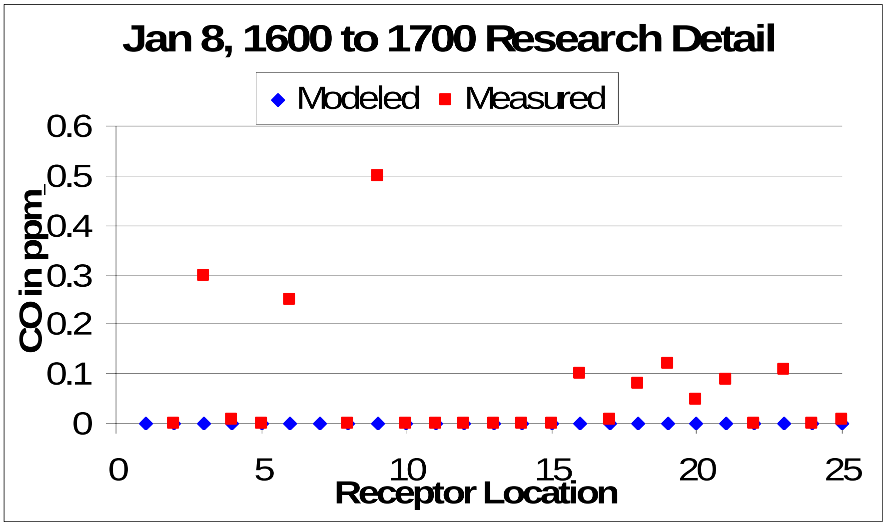

Figure 69 Measured Versus Modeled Research Detail: January 8, 2002 4pm to 5pm

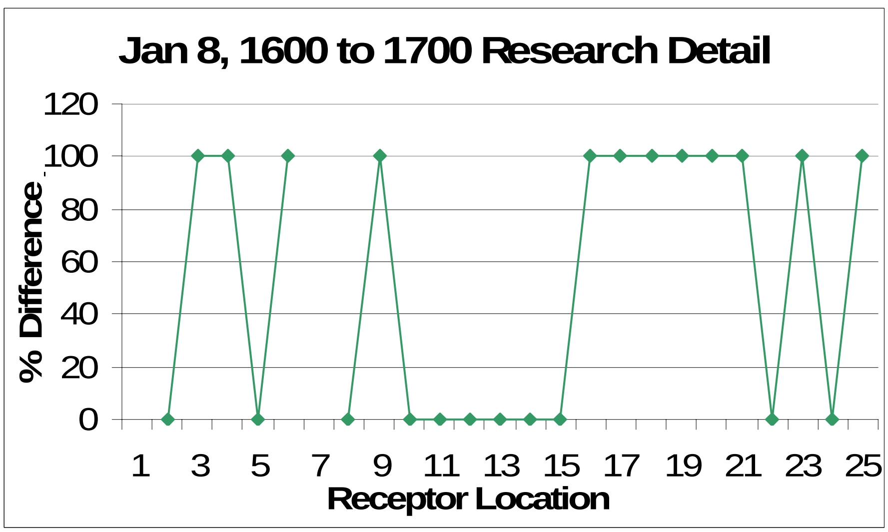

Figure 70 Measured vs. Modeled Research Detail % Difference: 1-8-2002 4pm to 5pm

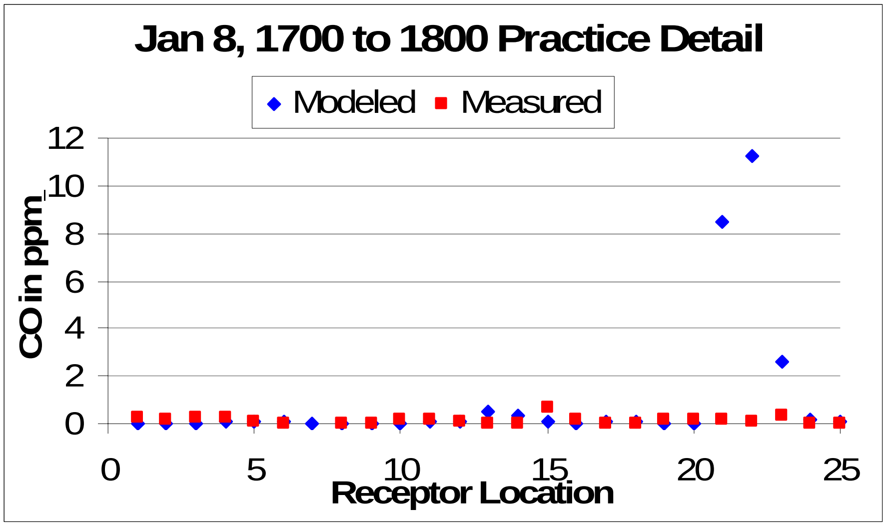

Figure 71 Measured Versus Modeled Practice Detail: January 8, 2002 5pm to 6pm

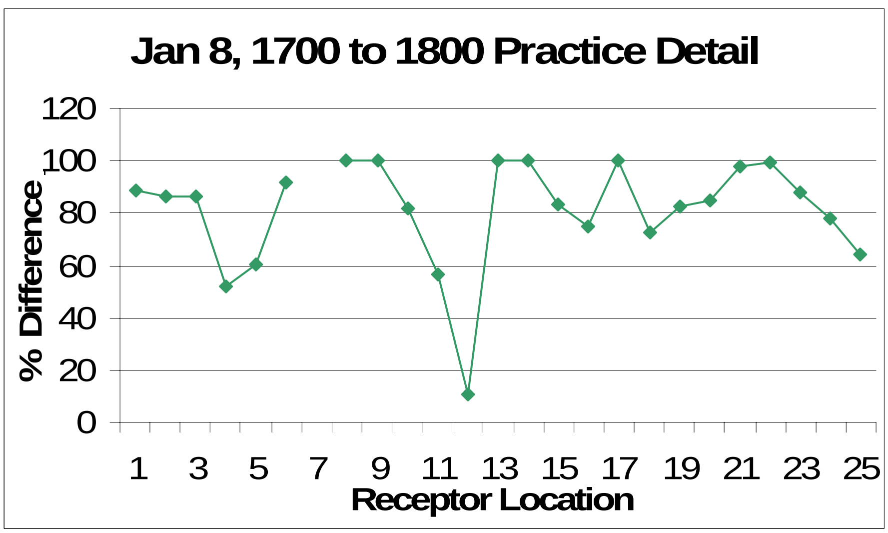

Figure 72 Measured vs. Modeled Practice Detail Percent Difference: 1-8-2002 5pm to 6pm

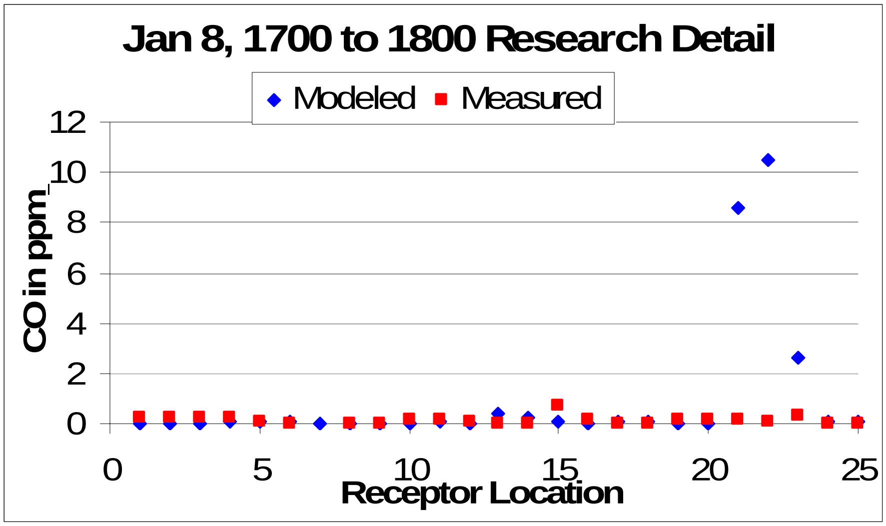

Figure 73 Measured Versus Modeled Research Detail: January 8, 2002 5pm to 6pm

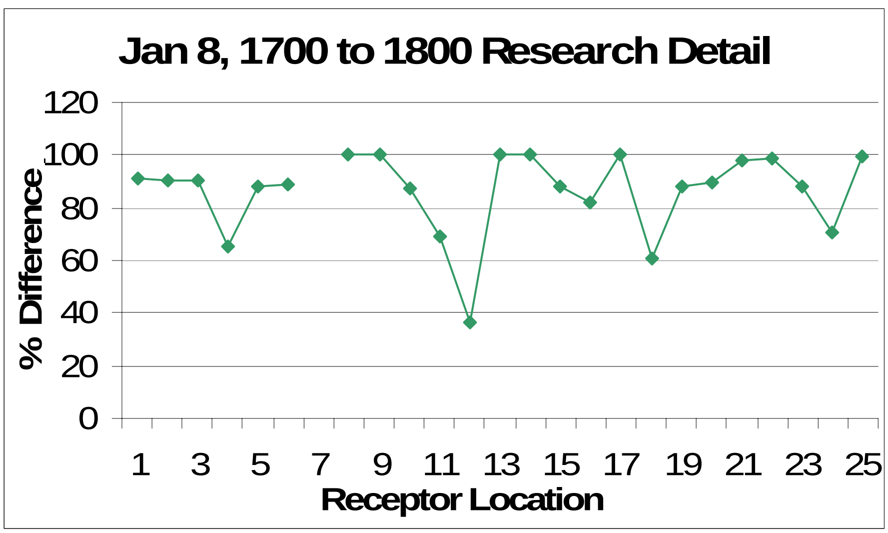

Figure 74 Measured vs. Modeled Research Detail % Difference: 1-8-2002 5pm to 6pm

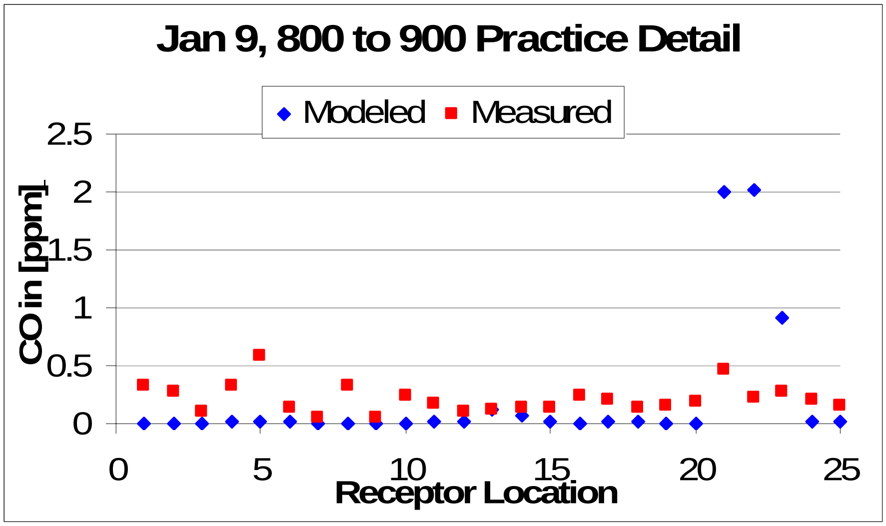

Figure 75 Measured Versus Modeled Practice Detail: January 9, 2002 8am to 9am

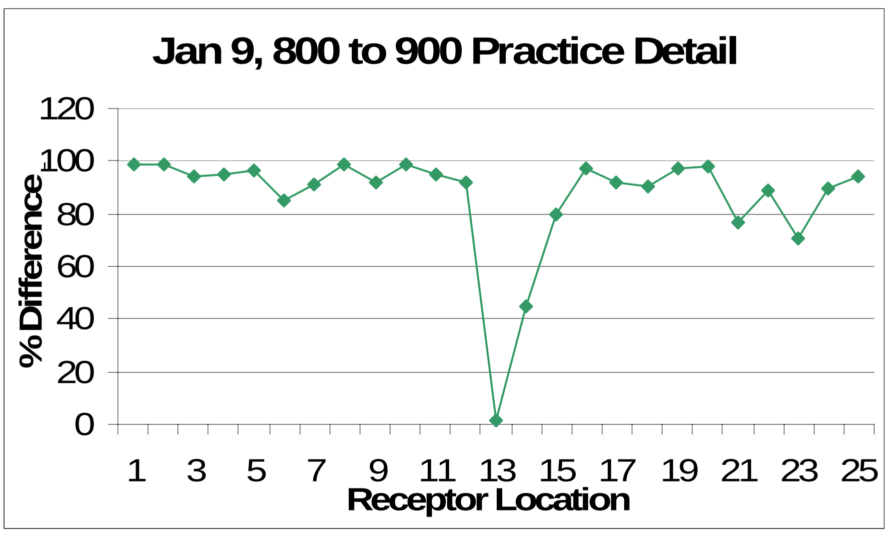

Figure 76 Measured vs. Modeled Practice Detail % Difference: 1-9-2002 8am to 9am

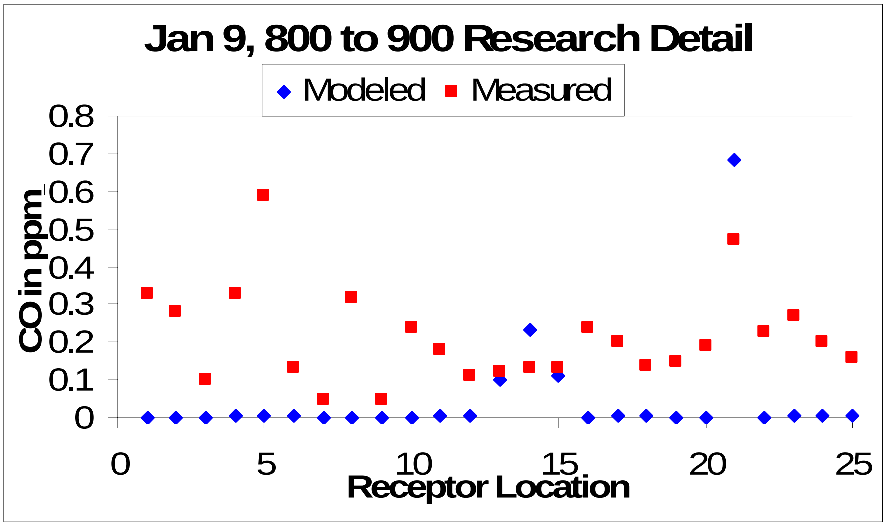

Figure 77 Measured Versus Modeled Research Detail: January 9, 2002 8am to 9am

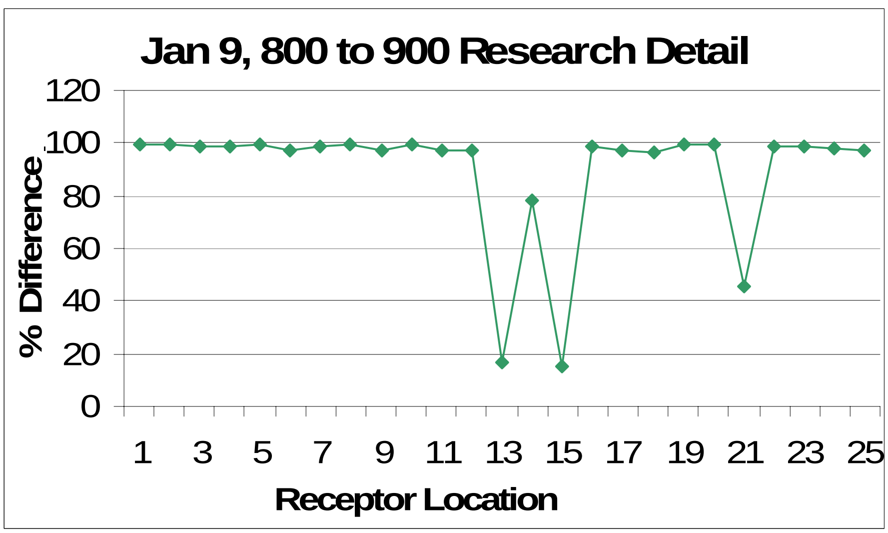

Figure 78 Measured vs. Modeled Research Detail % Difference: 1-9-2002 8am to 9am

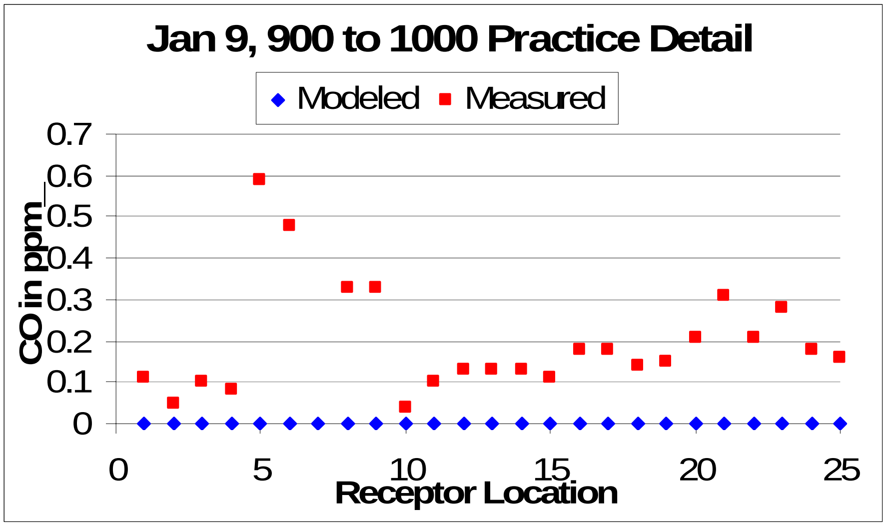

Figure 79 Measured Versus Modeled Practice Detail: January 9, 2002 9am to 10am

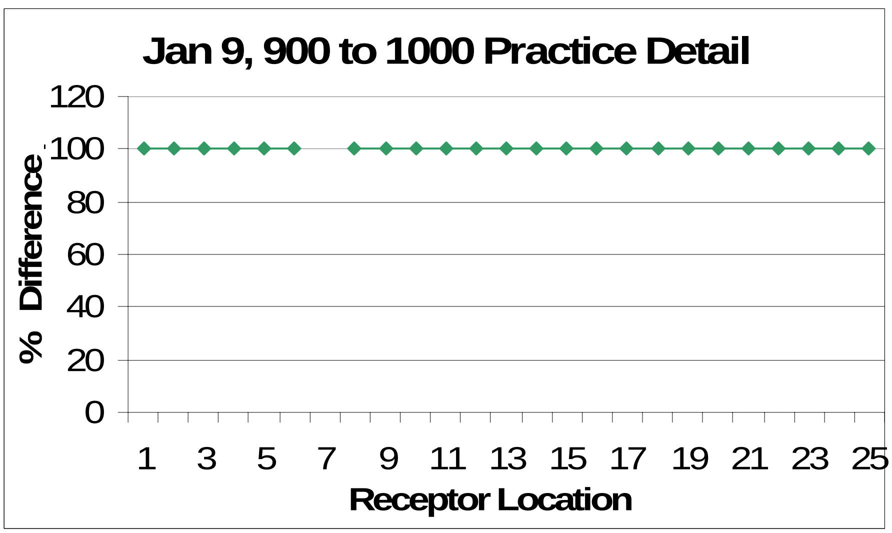

Figure 80 Measured vs. Modeled Practice Detail % Difference: 1-9-2002 9am to10am

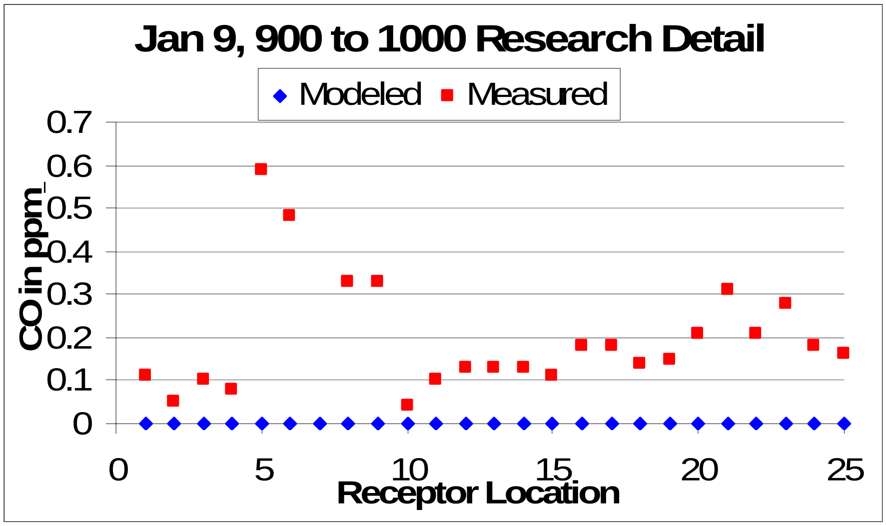

Figure 81 Measured Versus Modeled Research Detail: January 9, 2002 9am to 10am

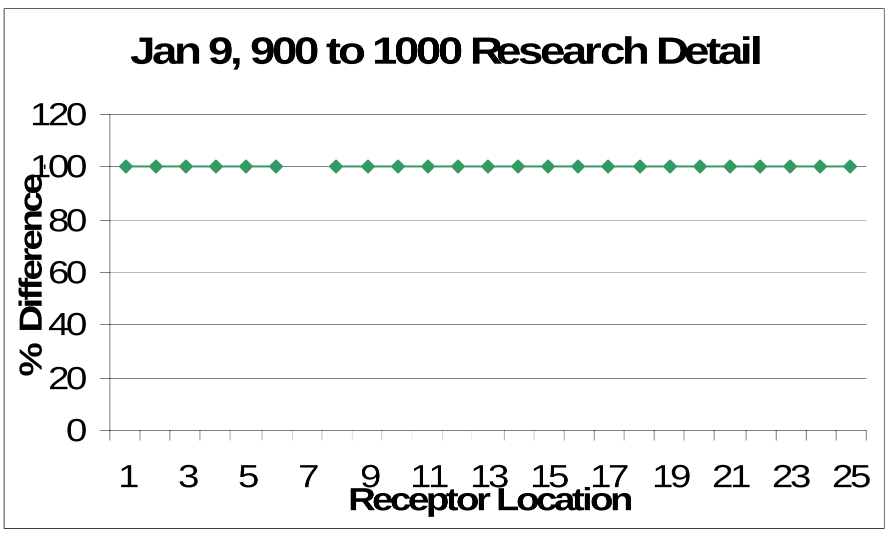

Figure 82 Measured vs. Modeled Research Detail % Difference: 1-9-2002 9am to 10am

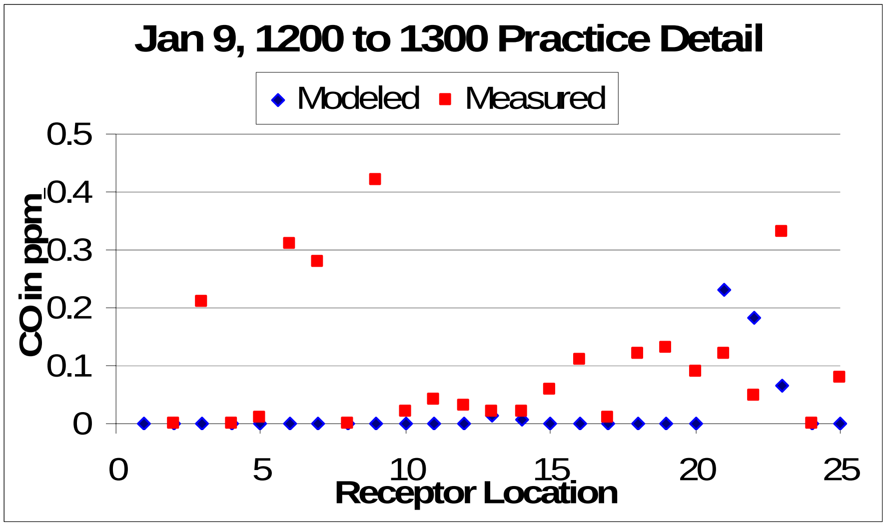

Figure 83 Measured Versus Modeled Practice Detail: January 9, 2002 12pm to 1pm

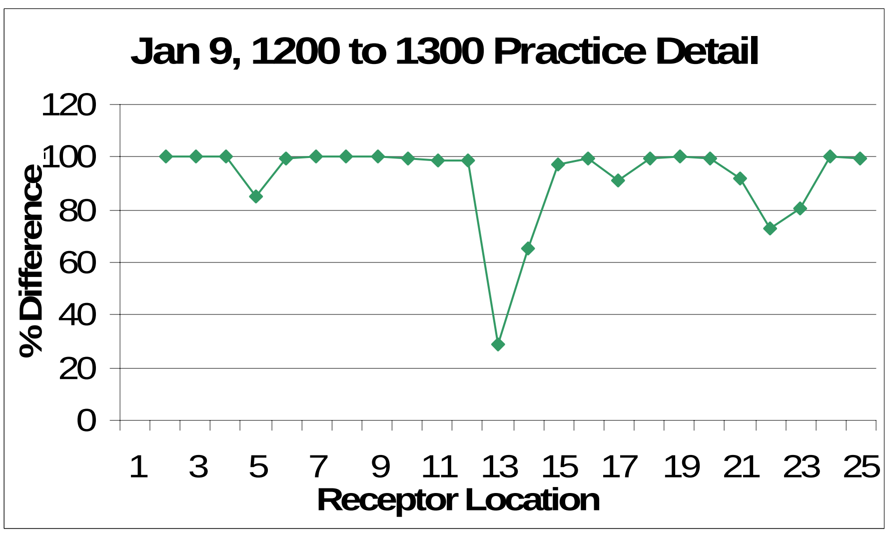

Figure 84 Measured vs. Modeled Practice Detail Percent Difference: 1-9-2002 12pm to 1pm

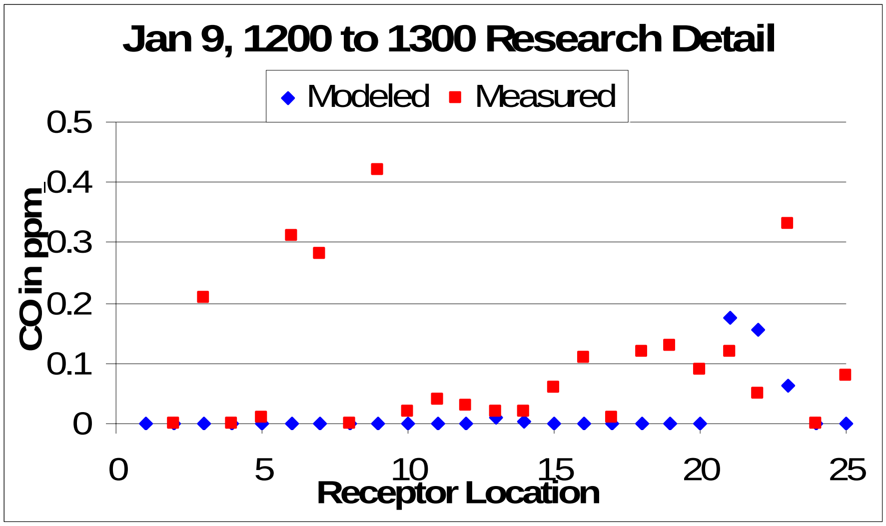

Figure 85 Measured Versus Modeled Research Detail: January 9, 2002 12pm to 1pm

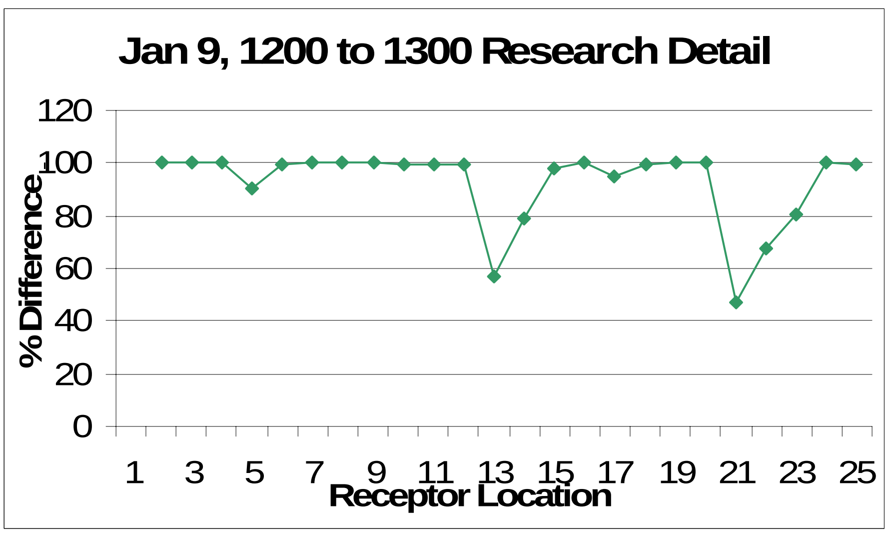

Figure 86 Measured vs. Modeled Research Detail % Difference: 1-9-2002 12pm to 1pm

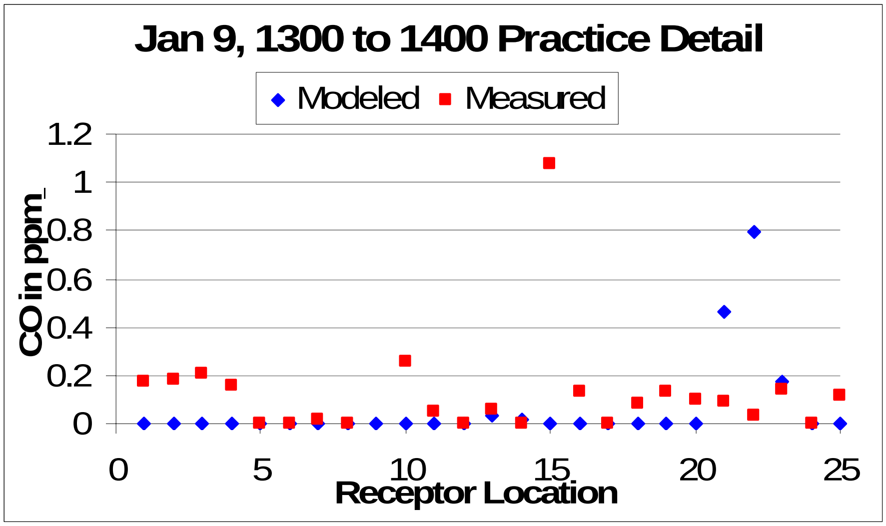

Figure 87 Measured Versus Modeled Practice Detail: January 9, 2002 1pm to 2pm

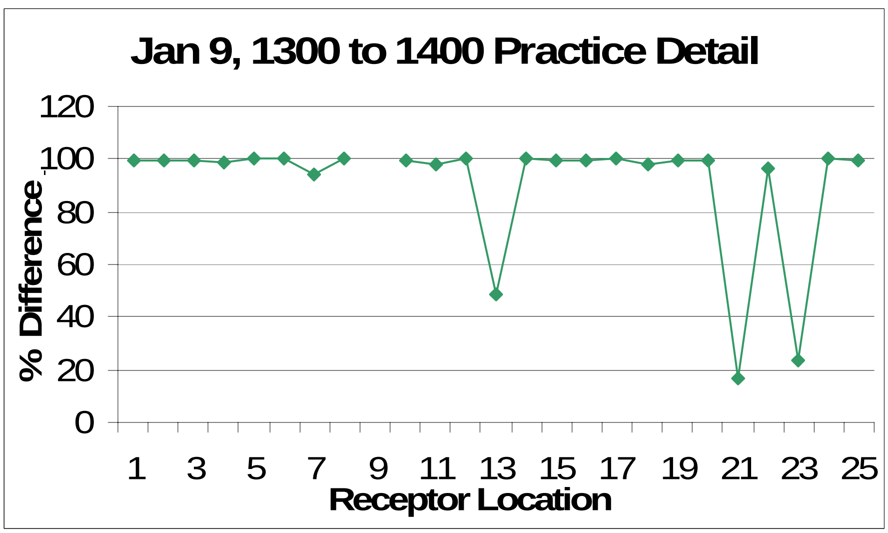

Figure 88 Measured vs Modeled Practice Detail % Difference: 1-9-2002 1pm to 2pm

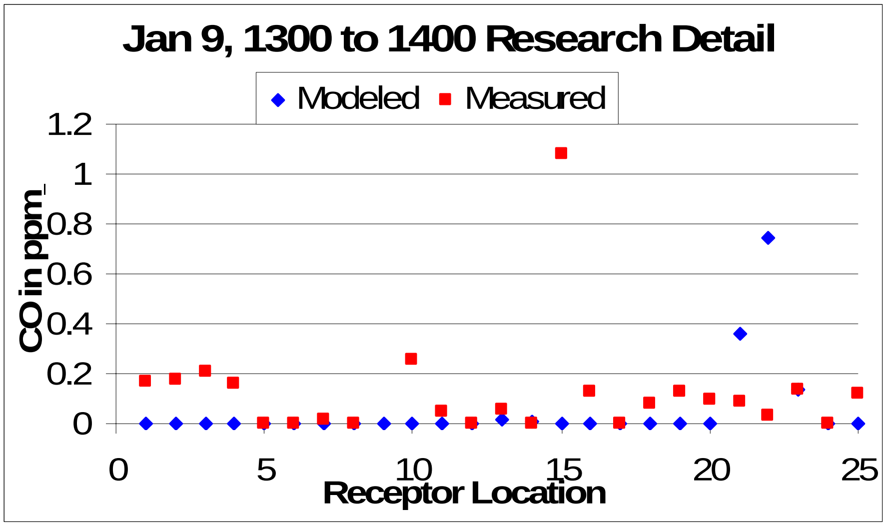

Figure 89 Measured Versus Modeled Research Detail: January 9, 2002 1pm to 2pm

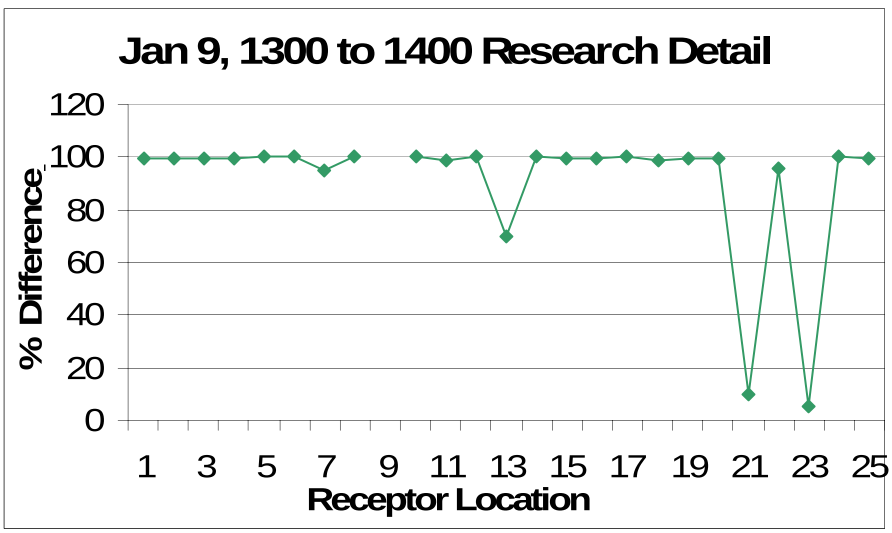

Figure 90 Measured vs. Modeled Research Detail Percent Difference: 1-9-2002 1pm to 2pm

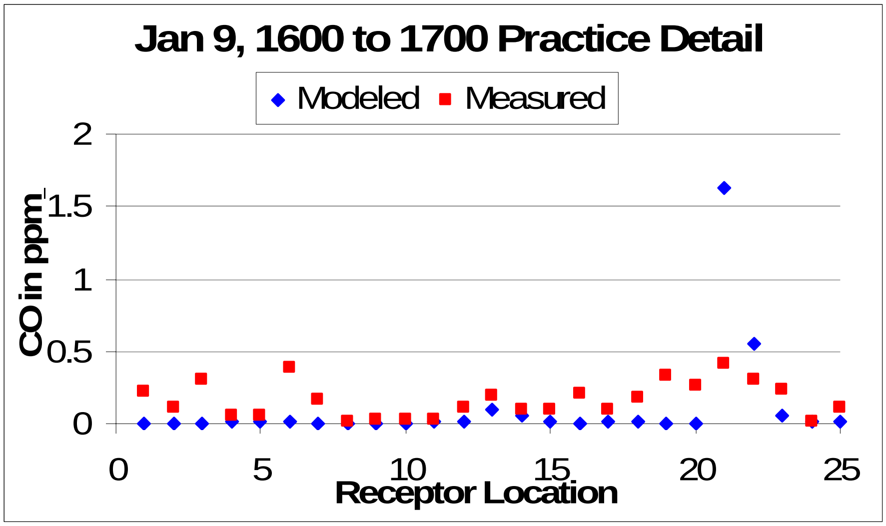

Figure 91 Measured Versus Modeled Practice Detail: January 9, 2002 4pm to 5pm

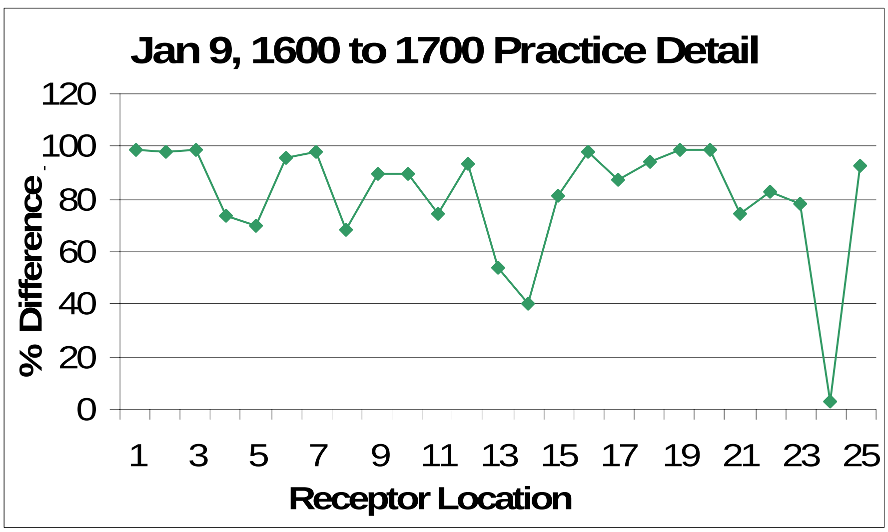

Figure 92 Measured vs. Modeled Practice Detail % Difference: 1-9-2002 4pm to 5pm

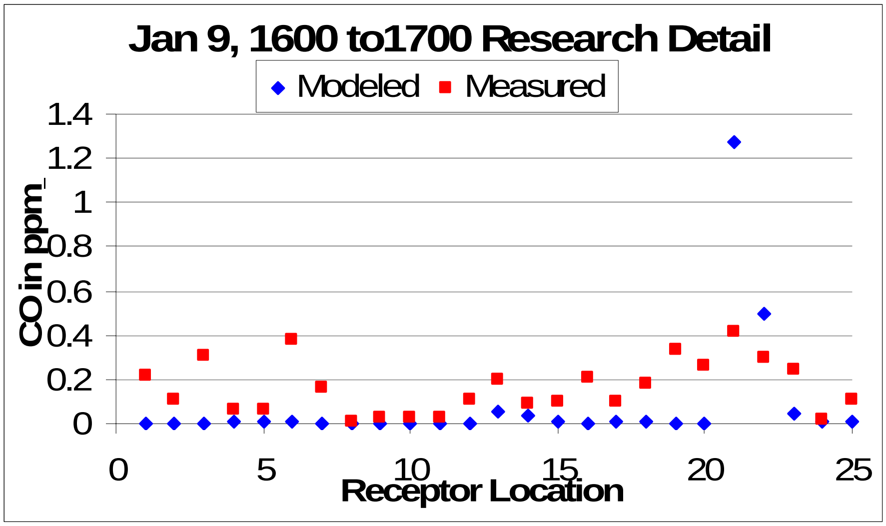

Figure 93 Measured Versus Modeled Research Detail: January 9, 2002 4pm to 5pm

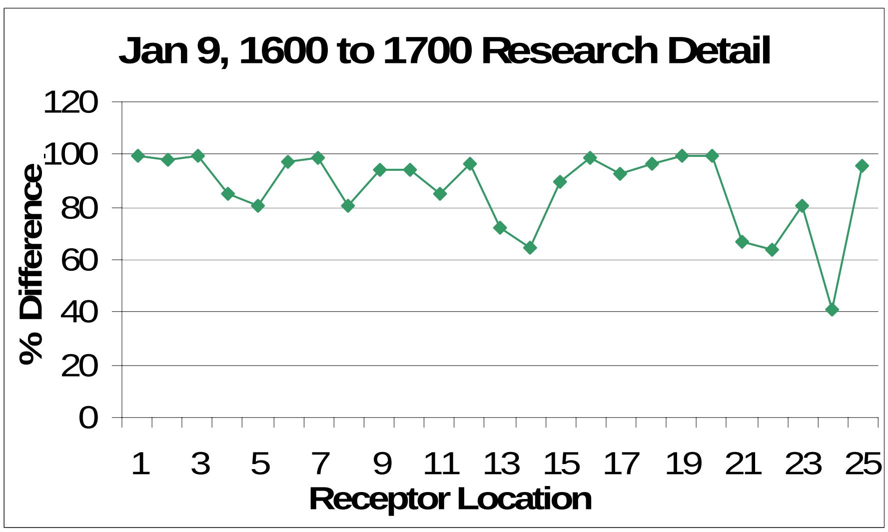

Figure 94 Measured vs. Modeled Research Detail % Difference: 1-9-2002 4pm

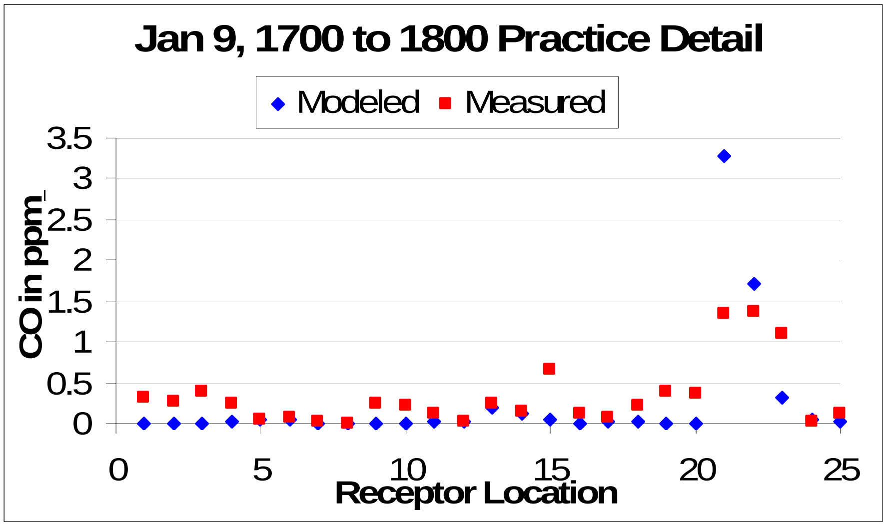

Figure 95 Modeled Practice Detail: January 9, 2002 5pm to 6pm

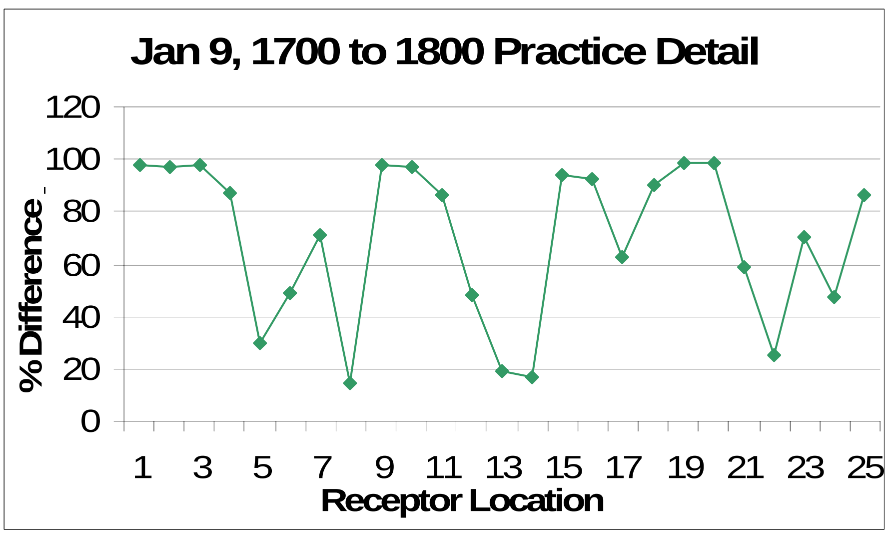

Figure 96 Measured vs. Modeled Practice Detail % Difference: 1-9-2002 5pm to 6pm

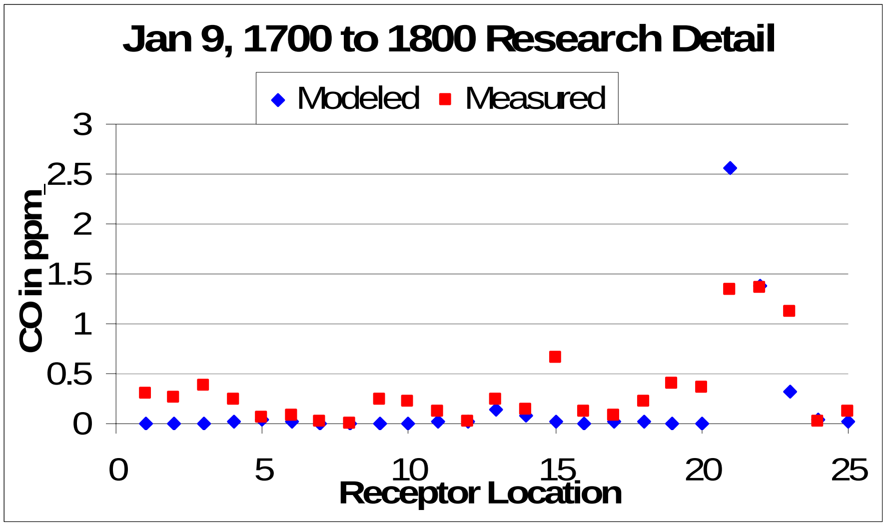

Figure 97 Measured Versus Modeled Research Detail: January 9, 2002 5pm to 6pm

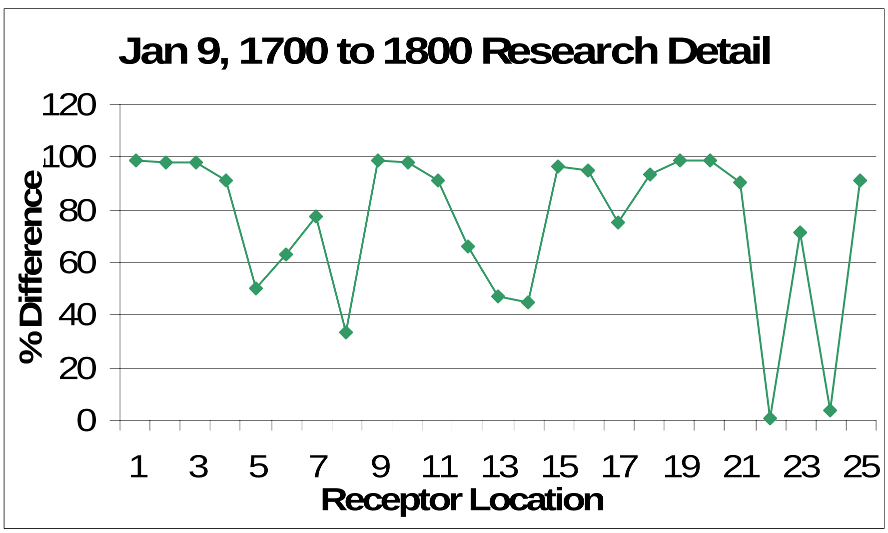

Figure 98 Measured vs. Modeled Research Detail %Difference: 1-9-2002 5pm to 6pm

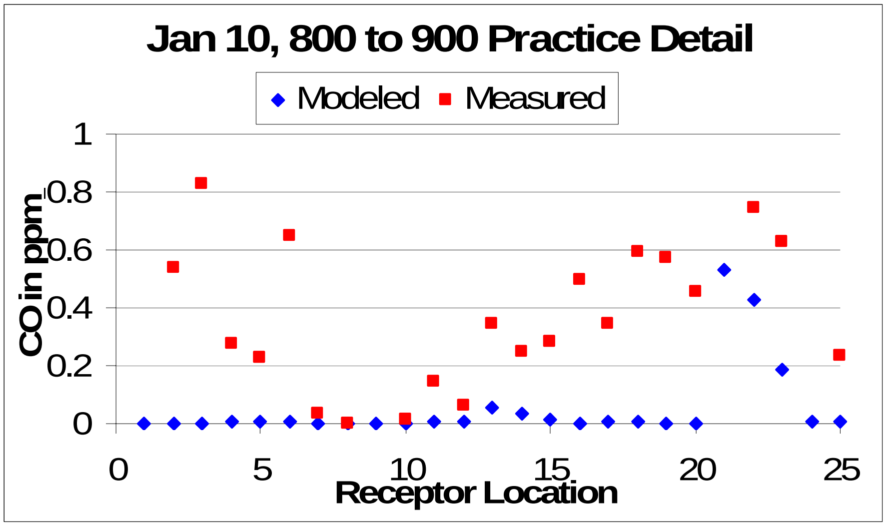

Figure 99 Measured Versus Modeled Practice Detail: January 10, 2002 8am to 9am

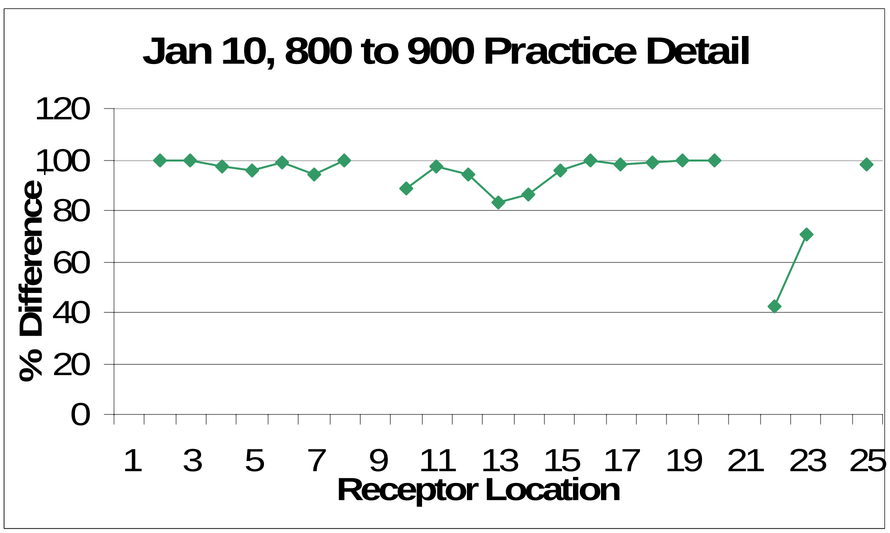

Figure 100 Measured vs. Modeled Practice Detail % Difference: 1-10-2002 8am to 9am

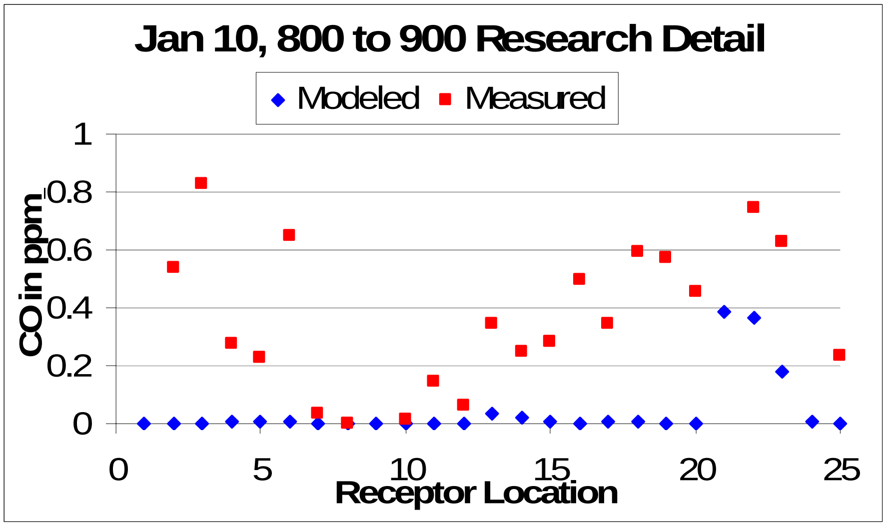

Figure 101 Measured Versus Modeled Research Detail: January 10, 2002 8am to 9am

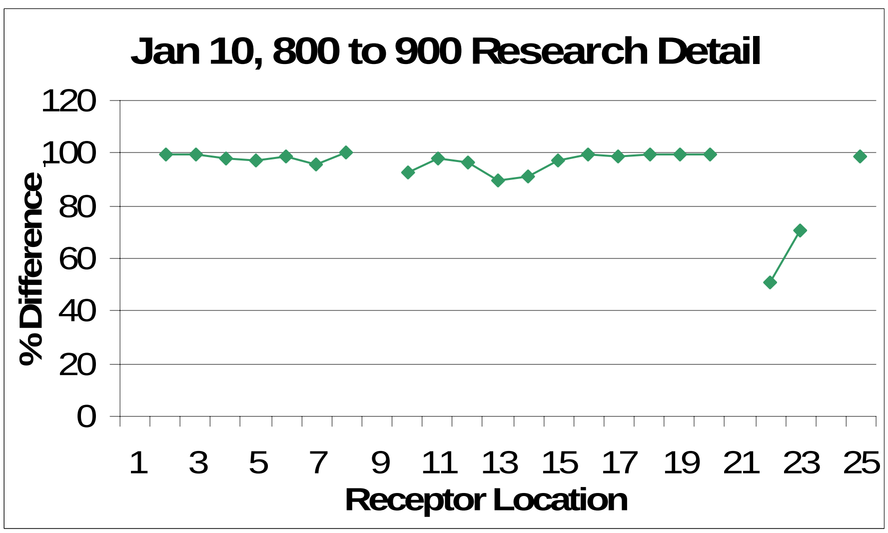

Figure 102 Measured vs. Modeled Research Detail % Difference: 1-10-2002 8am to 9am

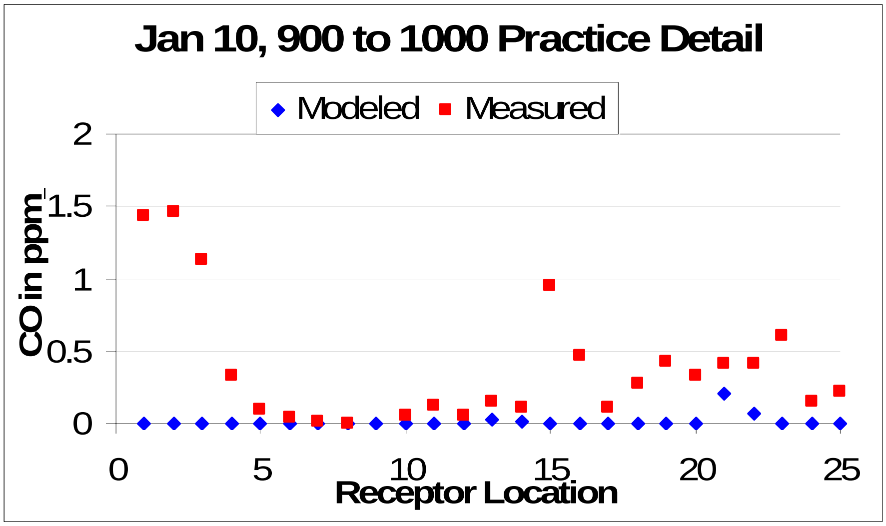

Figure 103 Measured Versus Modeled Practice Detail: January 10, 2002 9am to 10am

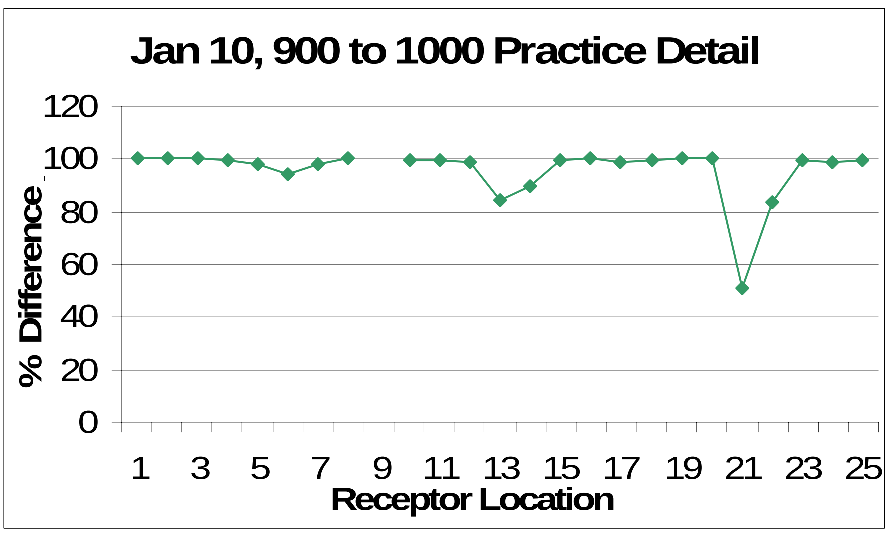

Figure 104 Measured vs. Modeled Practice Detail % Difference: 1-10-2002 9am to10am

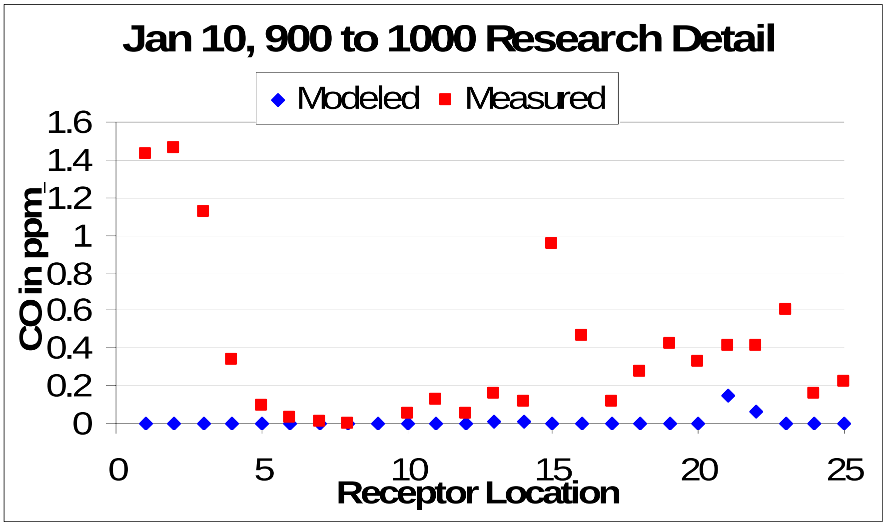

Figure 105 Measured Versus Modeled Research Detail: January 9, 2002 9am to 10am

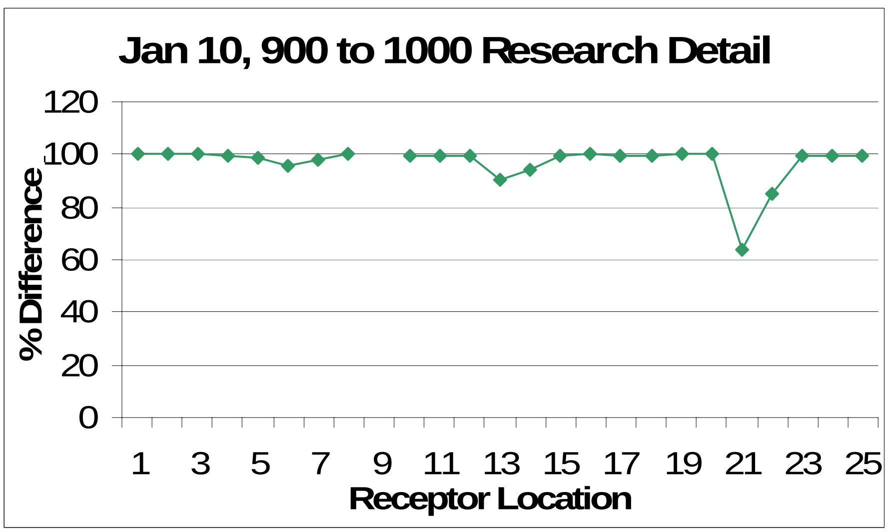

Figure 106 Measured vs. Modeled Research Detail % Difference: 1-10-2002 9am to 10am

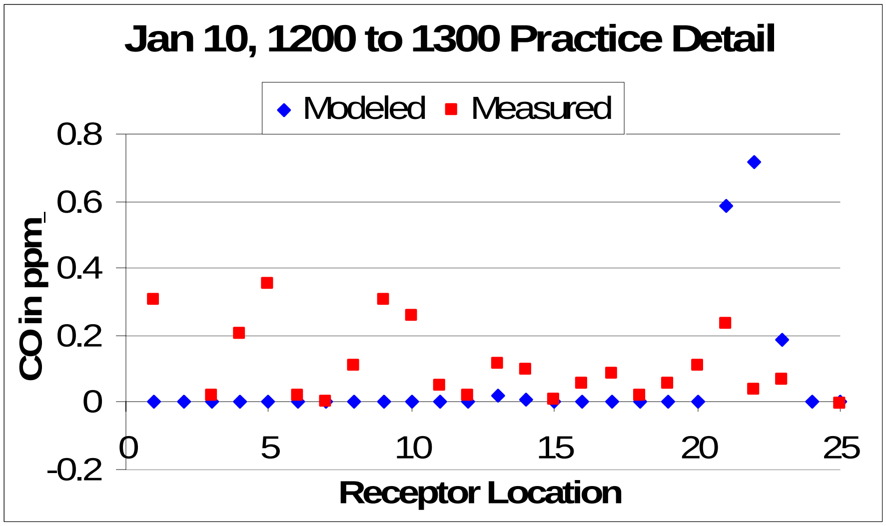

Figure 107 Measured Versus Modeled Practice Detail: January 10, 2002 12pm to 1pm

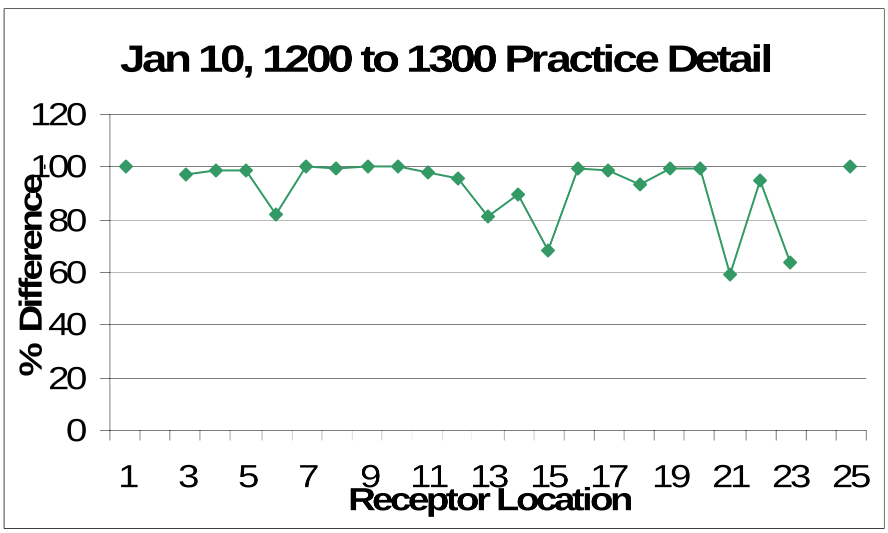

Figure 108 Measured Versus Modeled Practice Detail % Difference: 1-10-2002 12 to 1

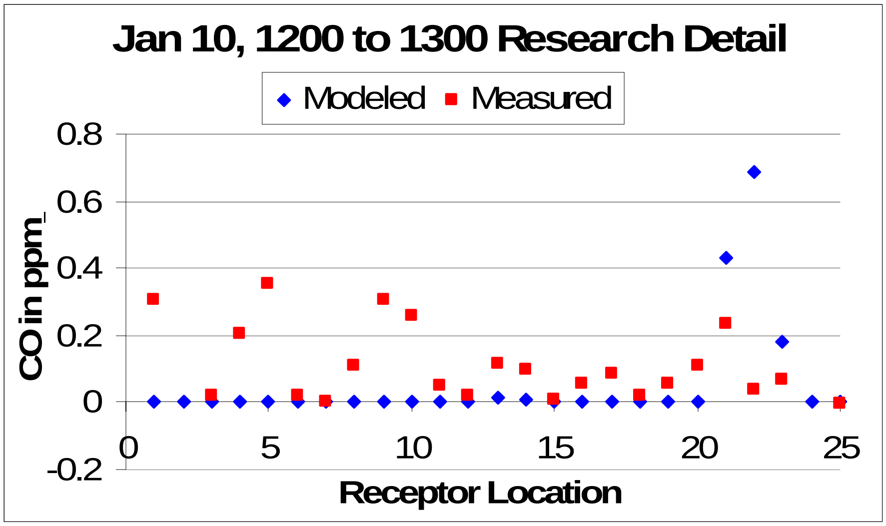

Figure 109 Measured Versus Modeled Research Detail: January 10, 2002 12pm to 1pm

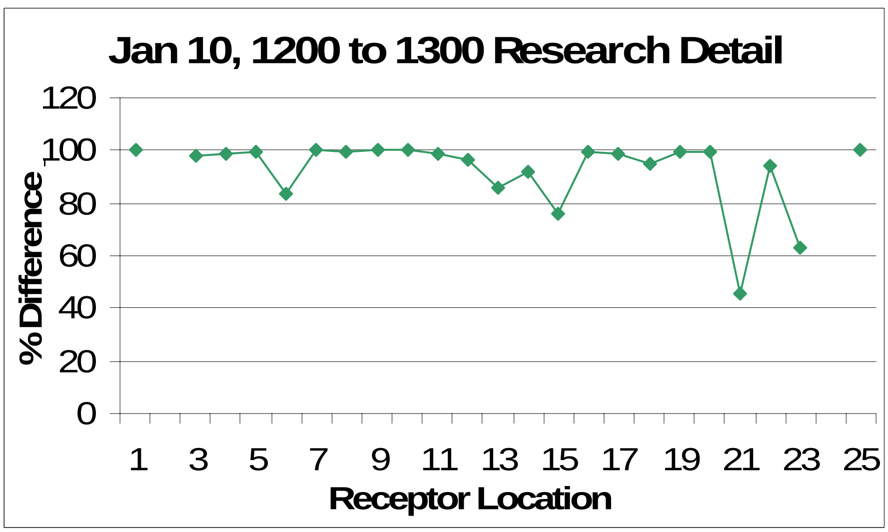

Figure 110 Measured vs. Modeled Research Detail % Difference: 1-10-2002 12pm to 1pm

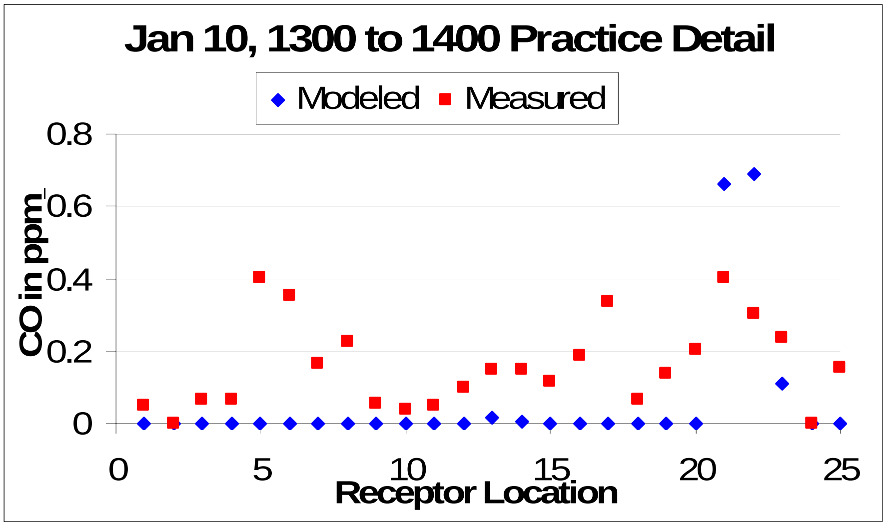

Figure 111 Measured Versus Modeled Practice Detail: January 10, 2002 1pm to 2pm

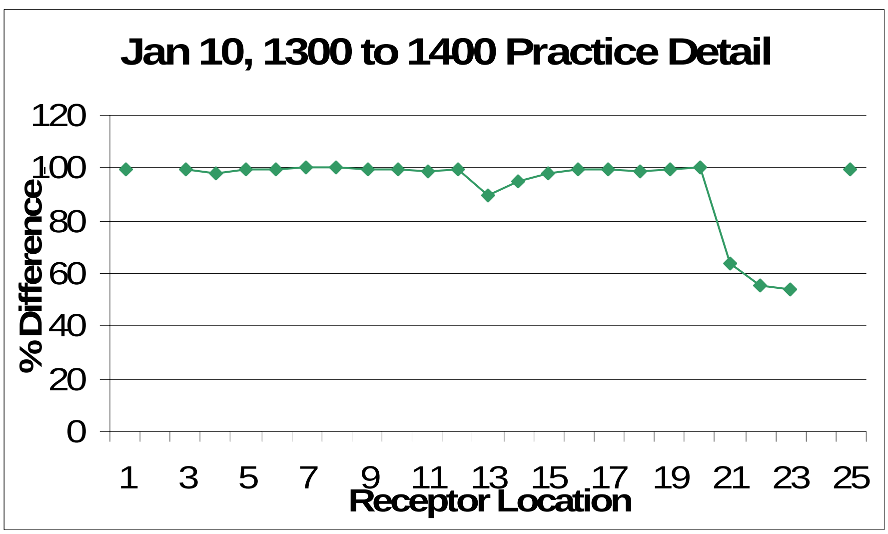

Figure 112 Measured vs Modeled Practice Detail % Difference: 1-10-2002 1pm to 2pm

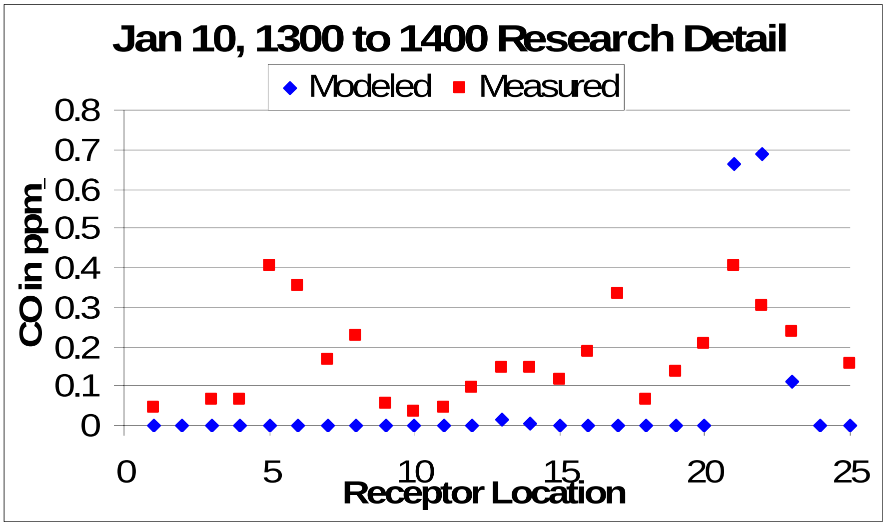

Figure 113 Measured Versus Modeled Research Detail: January 10, 2002 1pm to 2pm

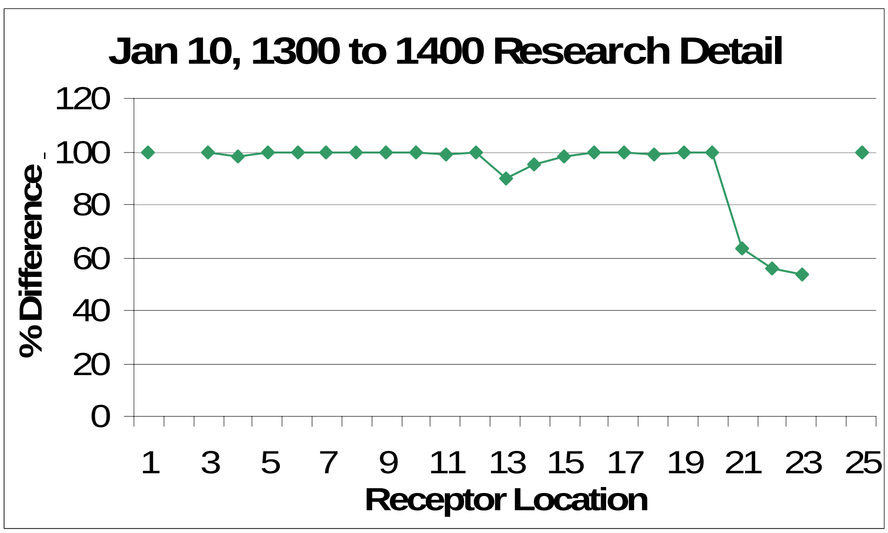

Figure 114 Measured vs. Modeled Research Detail % Difference: 1-10-2002 1pm to 2pm

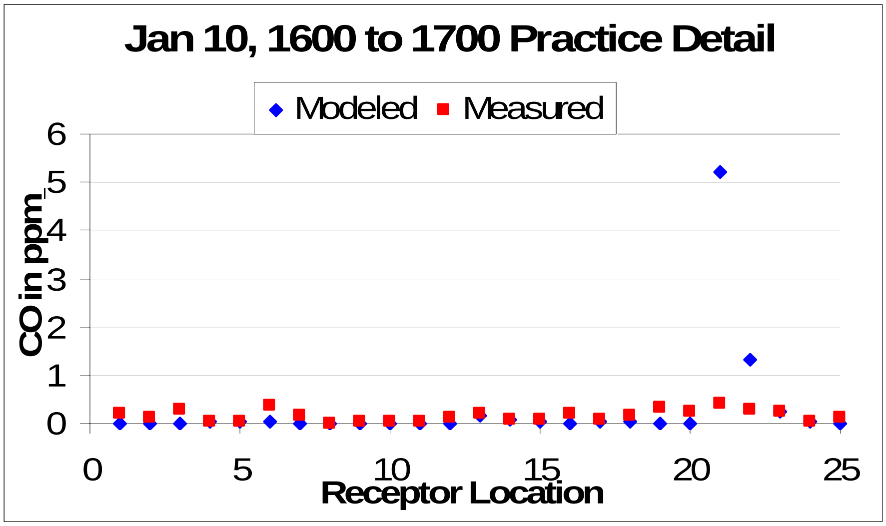

Figure 115 Measured Versus Modeled Practice Detail: January 10, 2002 4pm to 5pm

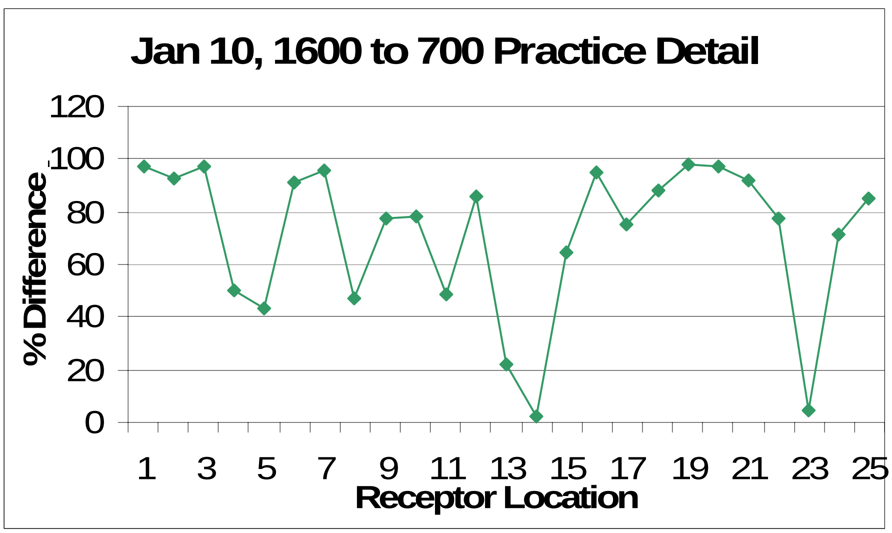

Figure 116 Measured vs. Modeled Practice Detail % Difference: 1-10-2002 4pm to 5pm

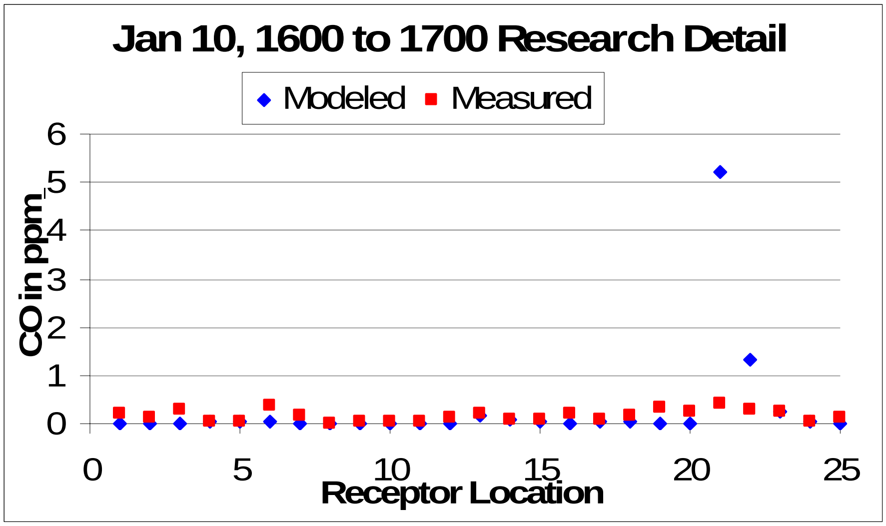

Figure 117 Measured Versus Modeled Research Detail: January 10, 2002 4pm to 5pm

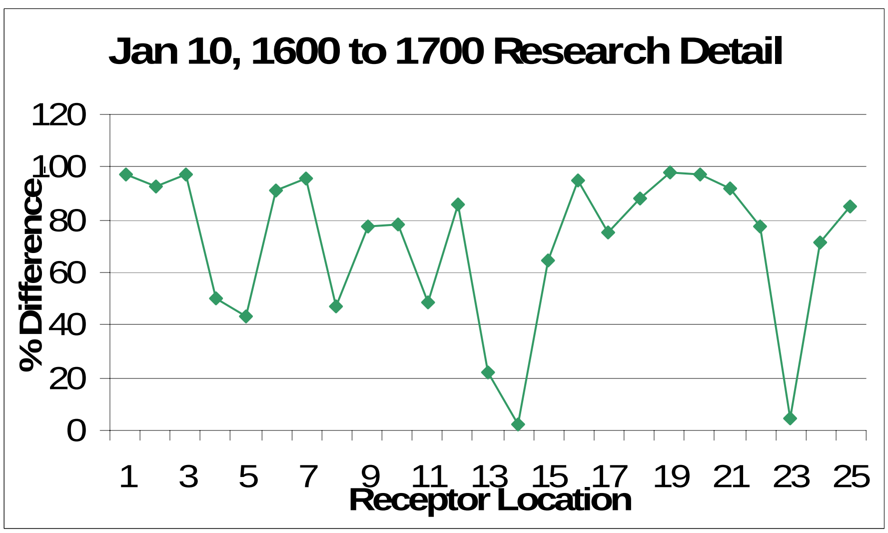

Figure 118 Measured vs Modeled Research Detail % Difference: 1-10-2002 4pm to 5pm

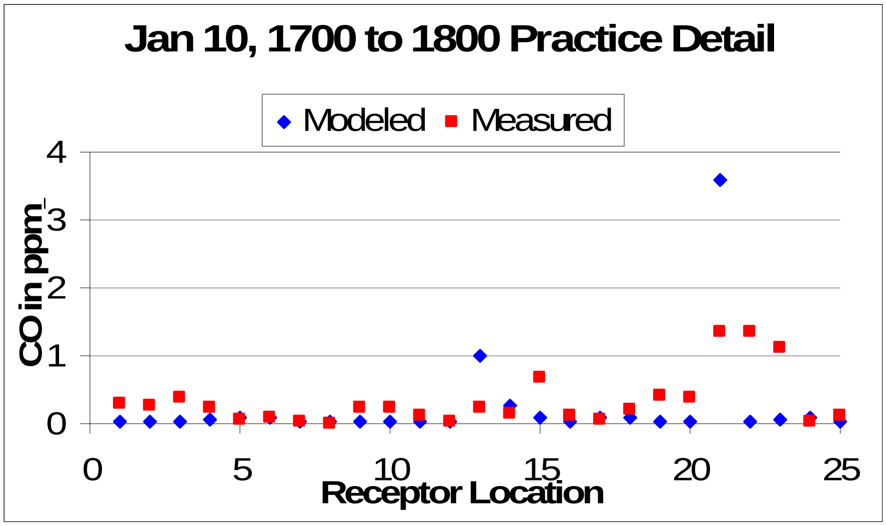

Figure 119 Measured Versus Modeled Practice Detail: January 10, 2002 5pm to 6pm

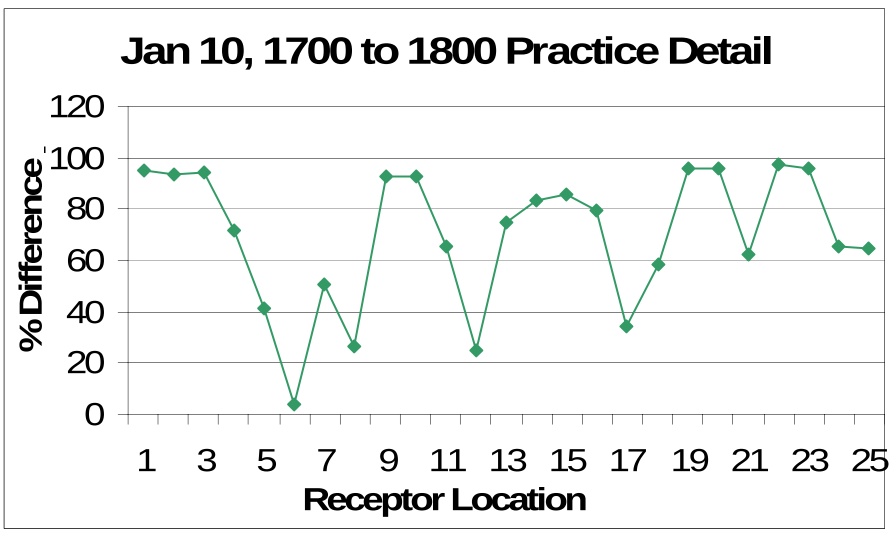

Figure 120 Measured vs. Modeled Practice Detail % Difference: 1-10-2002 5pm to 6pm

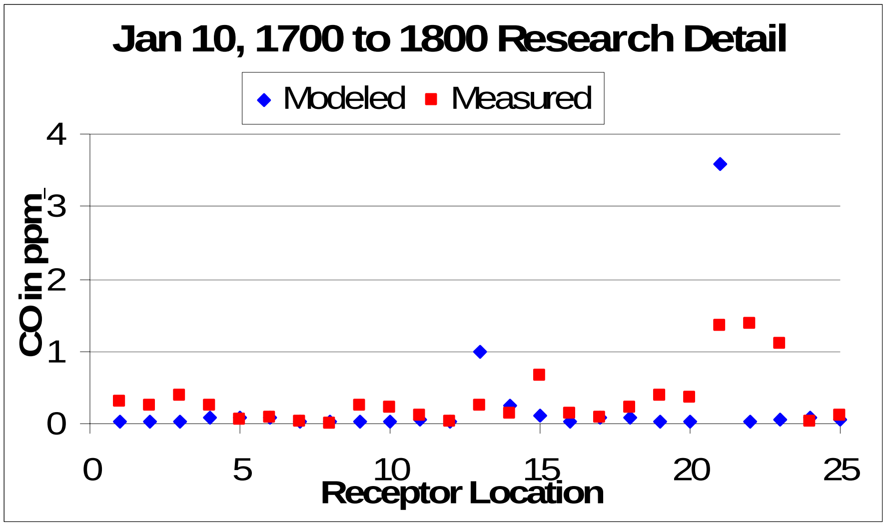

Figure 121 Measured Versus Modeled Research Detail: January 10, 2002 5pm to 6pm

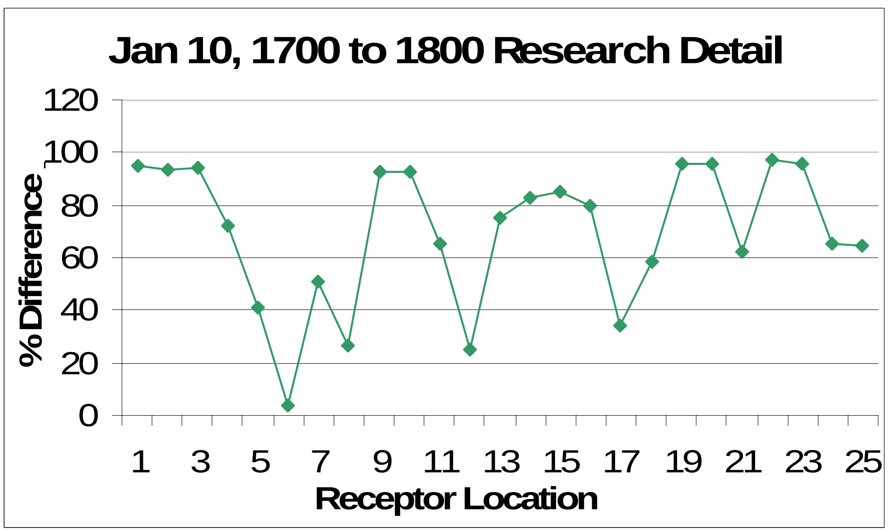

Figure 122 Measured vs. Modeled Research Detail % Difference: 1-10-2002 5pm to 6pm

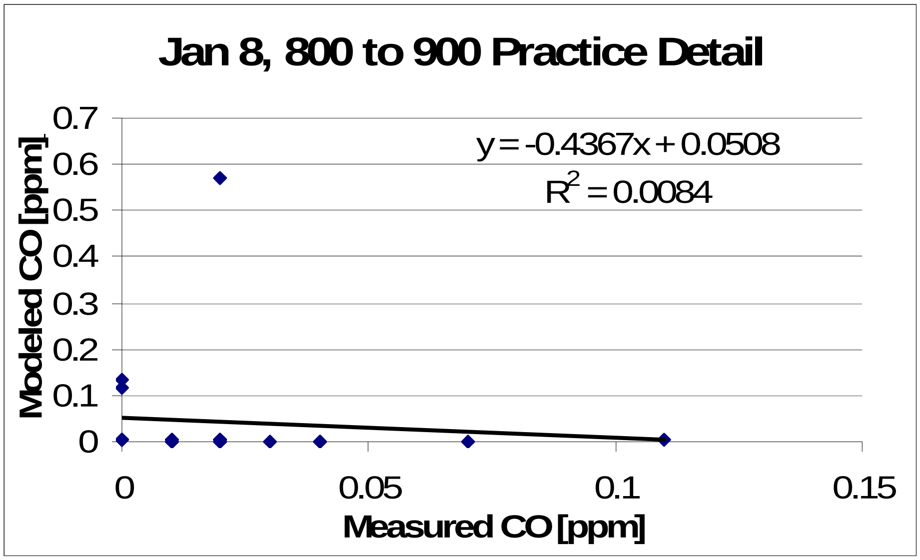

Figure 123 Jan 8, 8 to 9 Practice Detail Modeling Linear Regression

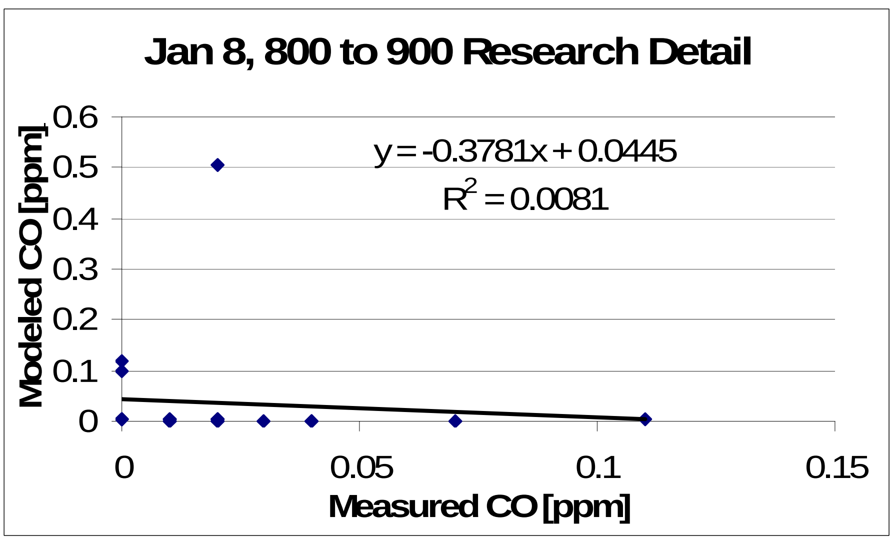

Figure 124 Jan 8, 8 to 9 Research Detail Modeling Linear Regression

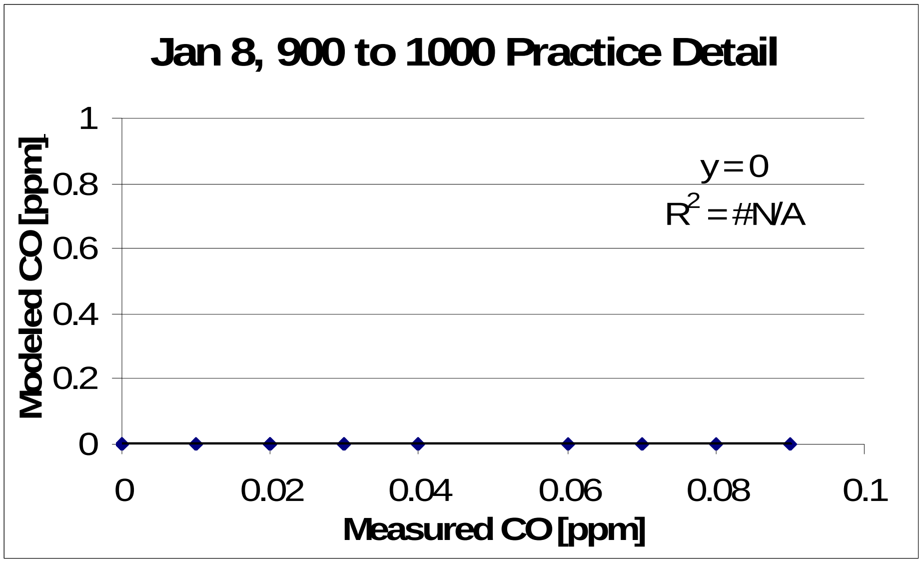

Figure 125 Jan 8, 9 to 10 Practice Detail Modeling Linear Regression

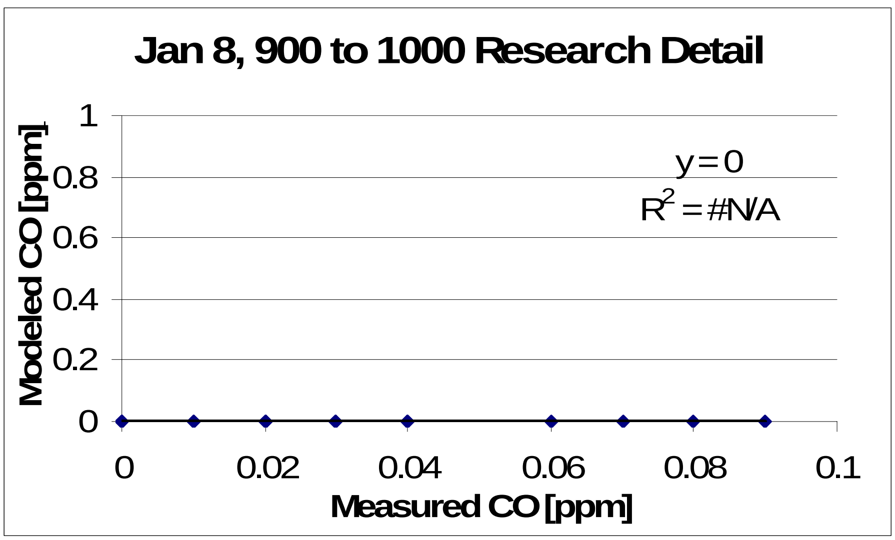

Figure 126 Jan 8, 9 to 10 Research Detail Modeling Linear Regression

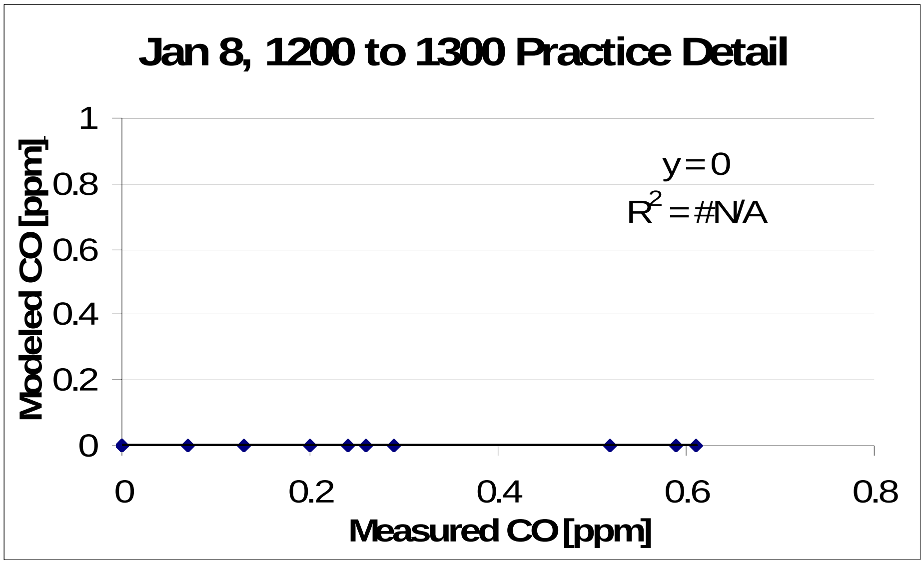

Figure 127 Jan 8, 12 to 1 Practice Detail Modeling Linear Regression

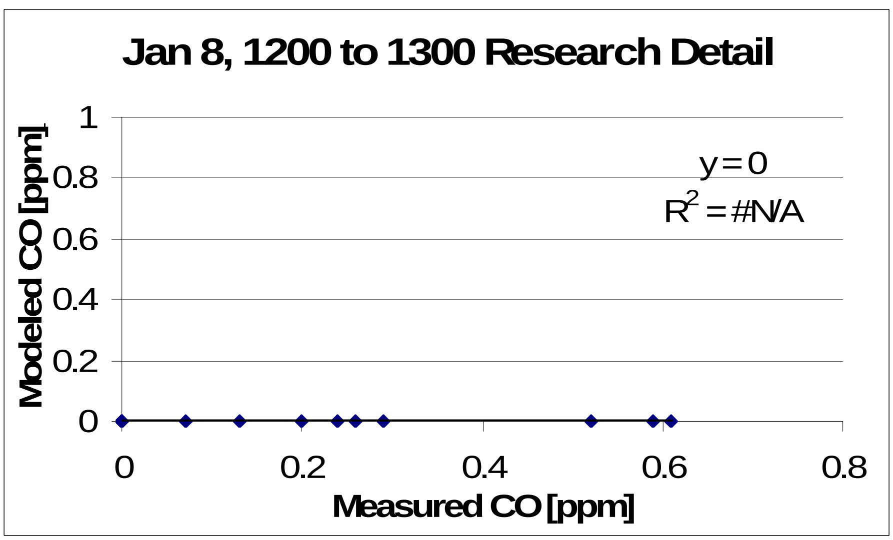

Figure 128 Jan 8, 12 to 1 Research Detail Modeling Linear Regression

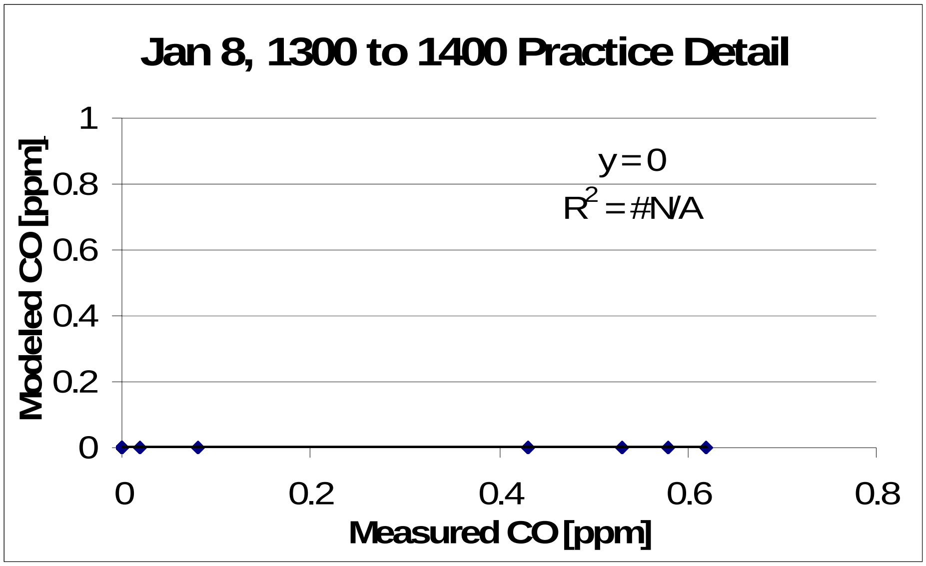

Figure 129 Jan 8, 1 to 2 Practice Detail Modeling Linear Regression

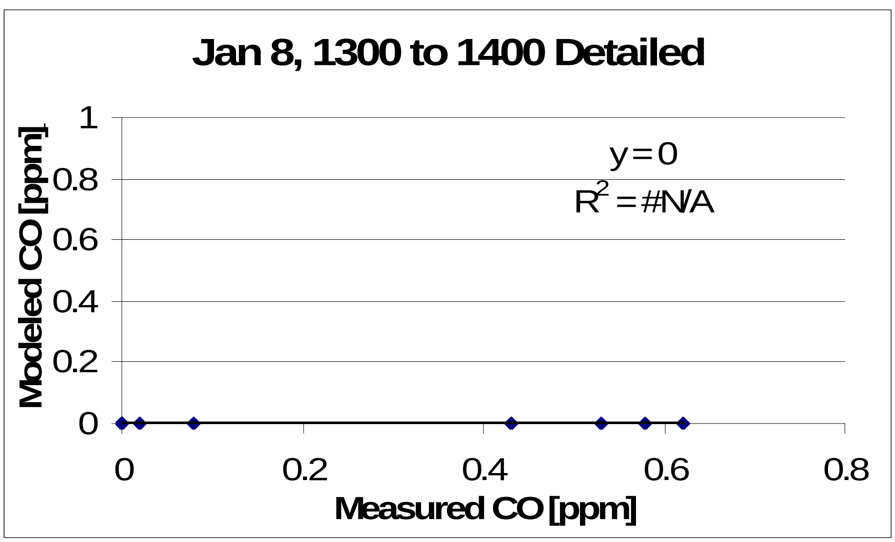

Figure 130 Jan 8, 1 to 2 Research Detail Modeling Linear Regression

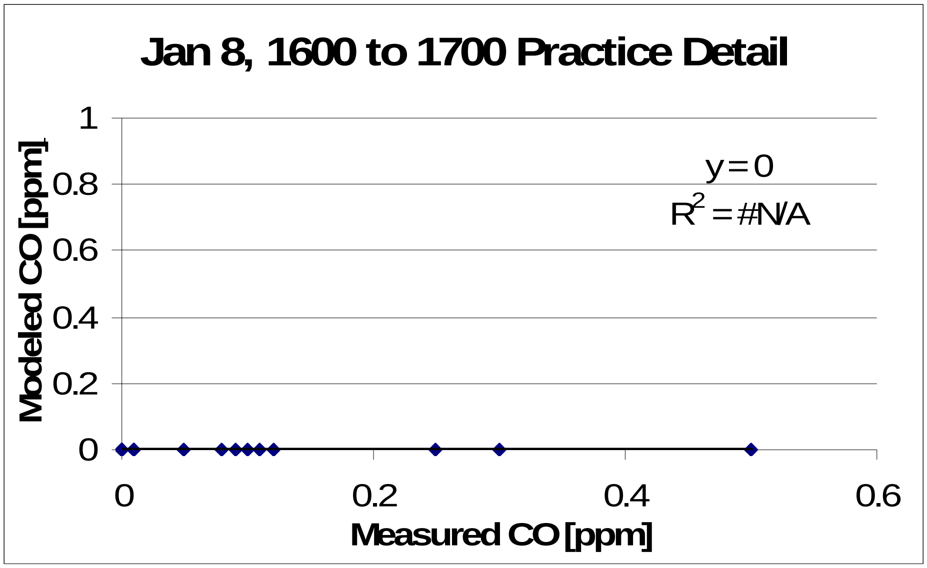

Figure 131 Jan 8, 4 to 5 Practice Detail Modeling Linear Regression

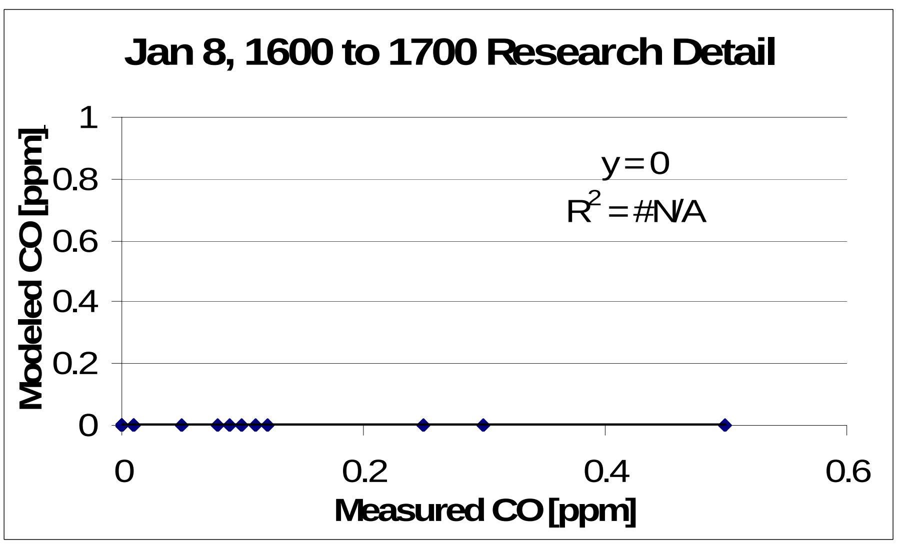

Figure 132 Jan 8, 4 to 5 Research Detail Modeling Linear Regression

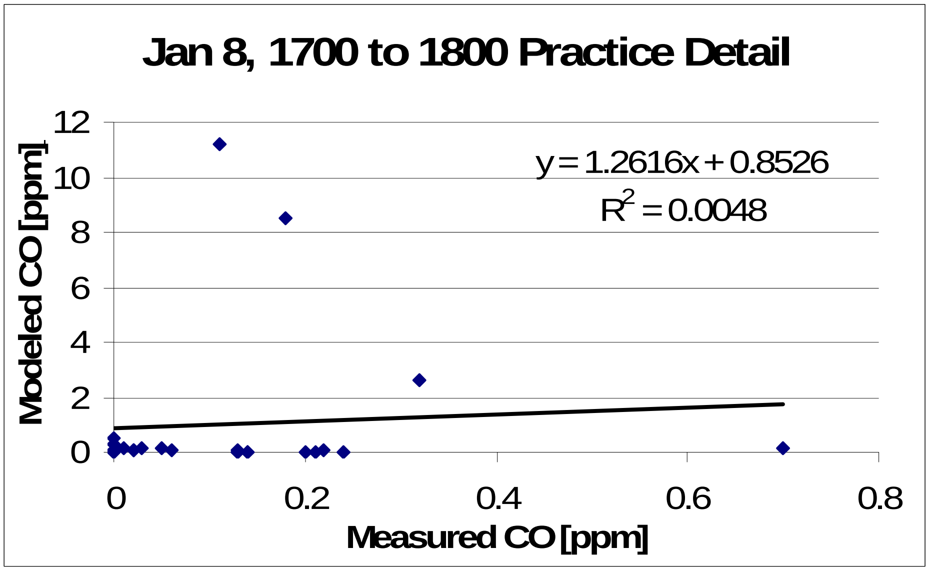

Figure 133 Jan 8, 5 to 6 Practice Detail Modeling Linear Regression

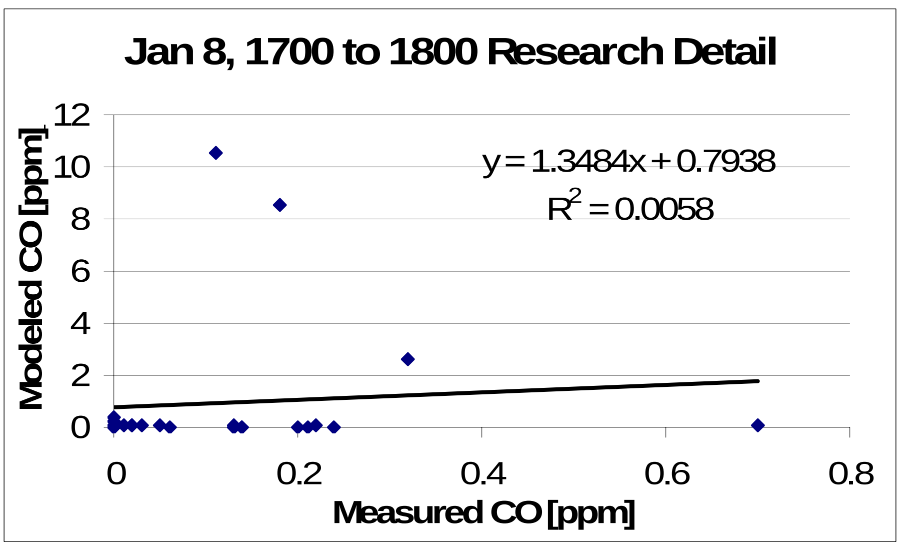

Figure 134 Jan 8, 5 to 6 Research Detail Modeling Linear Regression

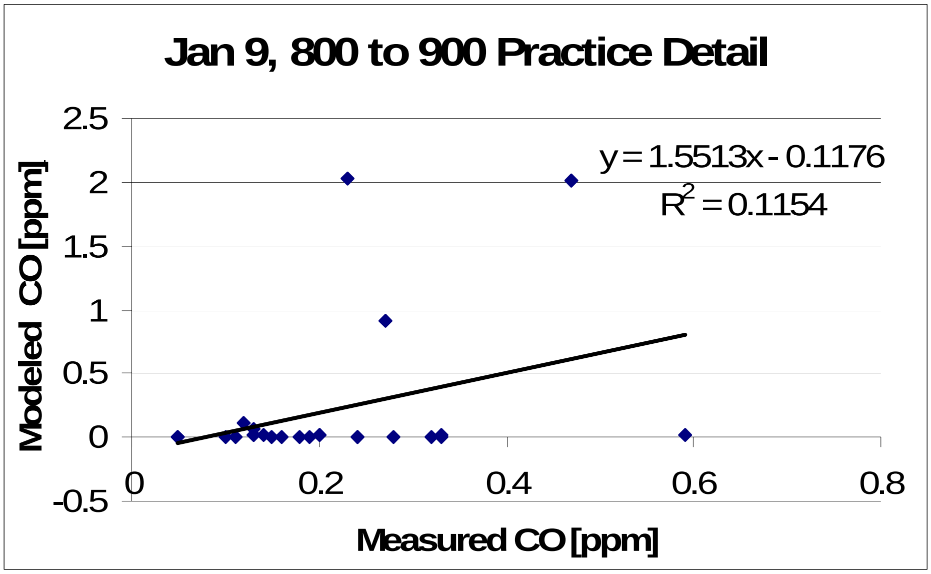

Figure 135 Jan 9, 8 to 9 Practice Detail Modeling Linear Regression

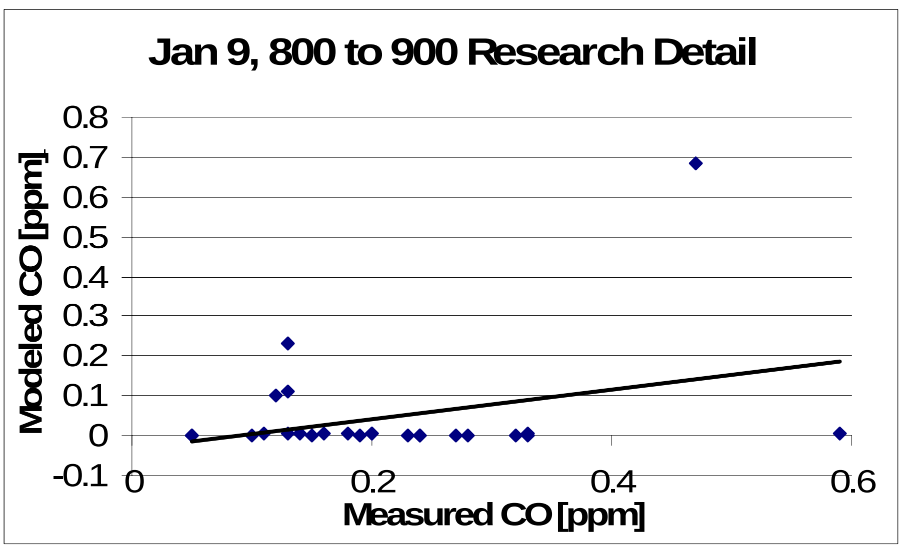

Figure 136 Jan 9, 8 to 9 Research Detail Modeling Linear Regression

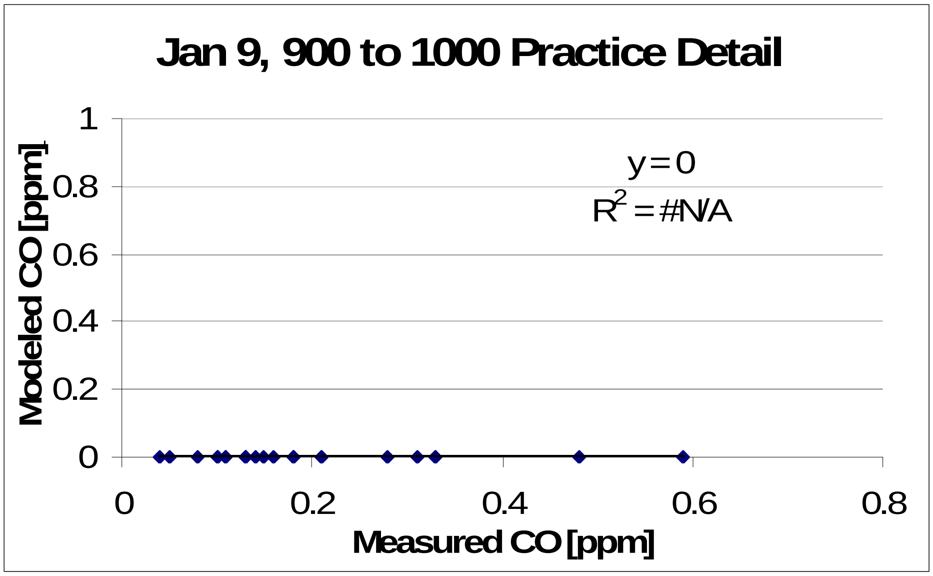

Figure 137 Jan 9, 9 to 10 Practice Detail Modeling Linear Regression

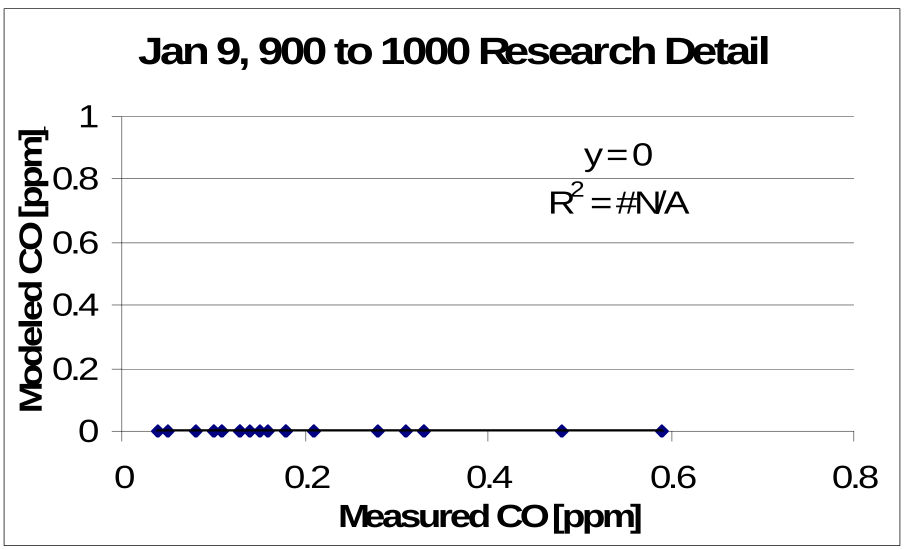

Figure 138 Jan 9, 9 to 10 Research Detail Modeling Linear Regression

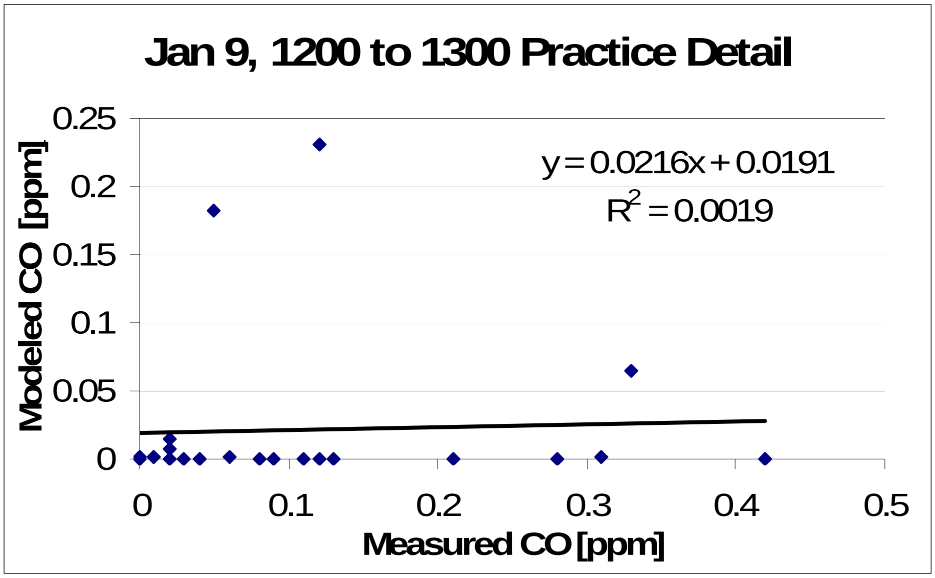

Figure 139 Jan 9, 12 to 1 Practice Detail Modeling Linear Regression

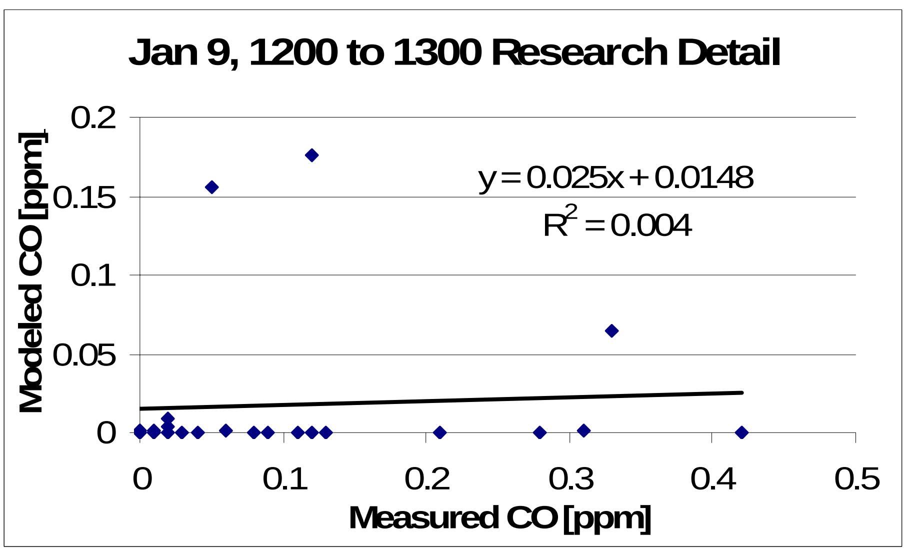

Figure 140 Jan 9, 12 to 1 Research Detail Modeling Linear Regression

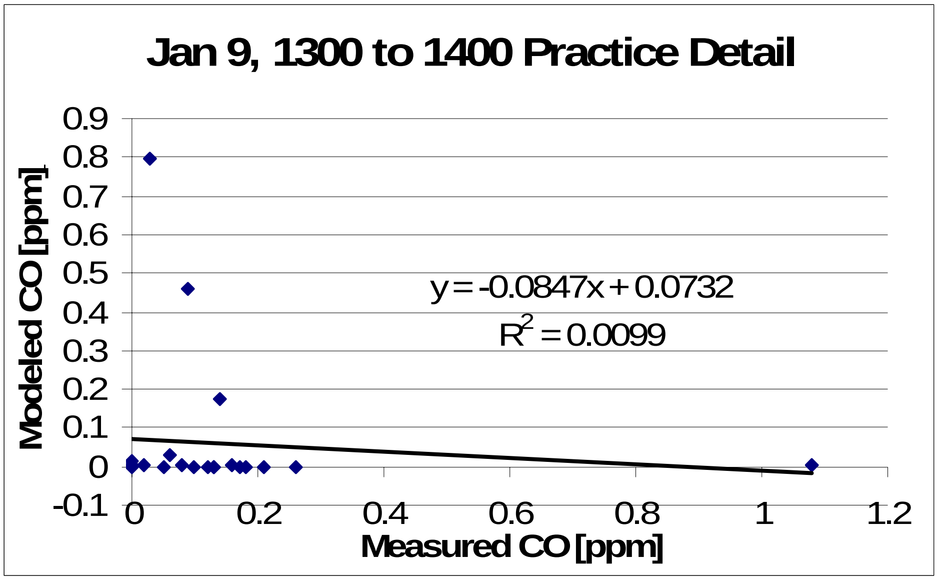

Figure 141 Jan 9, 1 to 2 Practice Detail Modeling Linear Regression

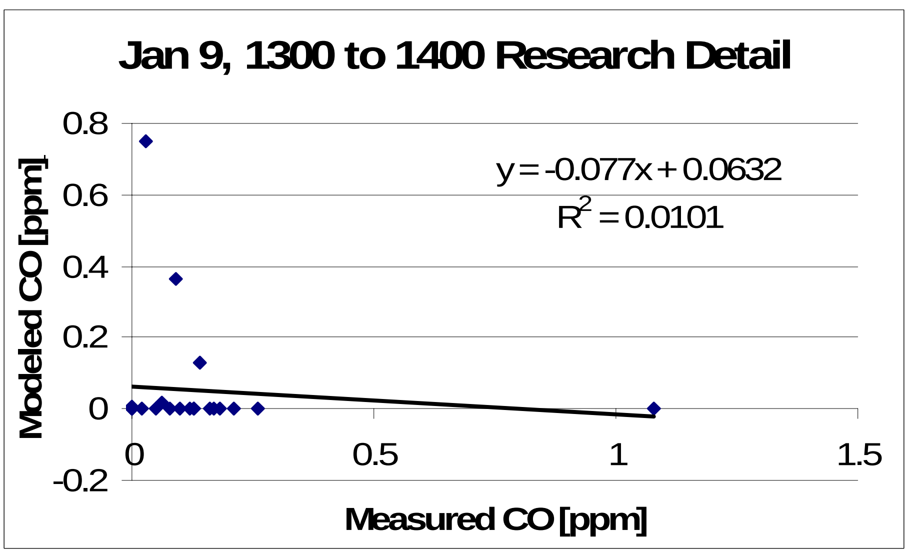

Figure 142 Jan 9, 1 to 2 Research Detail Modeling Linear Regression

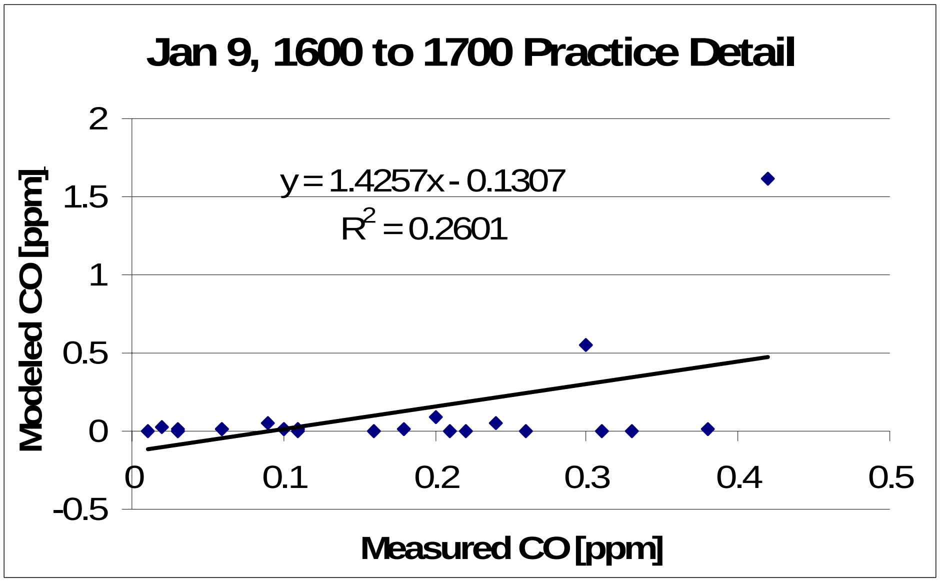

Figure 143 Jan 9, 4 to 5 Practice Detail Modeling Linear Regression

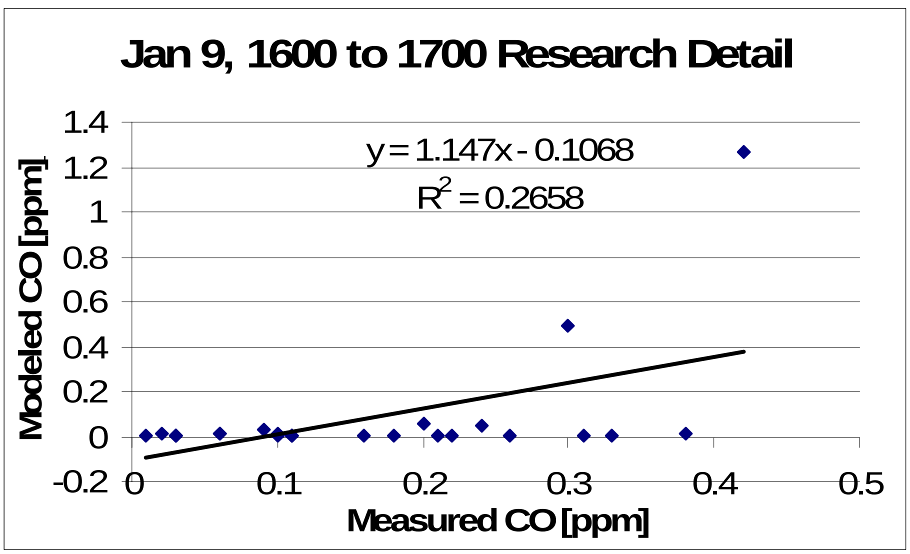

Figure 144 Jan 9, 4 to 5 Research Detail Modeling Linear Regression

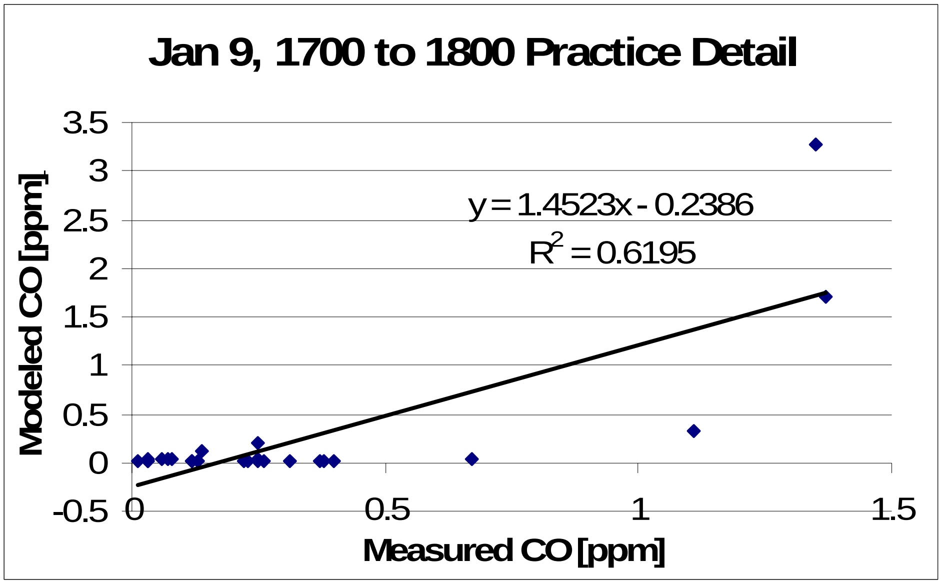

Figure 145 Jan 9, 5 to 6 Practice Detail Modeling Linear Regression

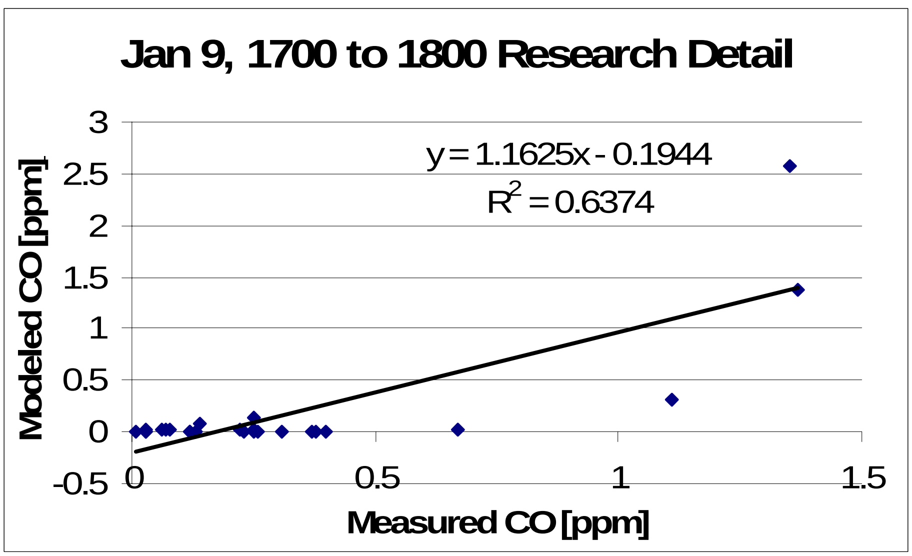

Figure 146 Jan 9, 5 to 6 Research Detail Modeling Linear Regression

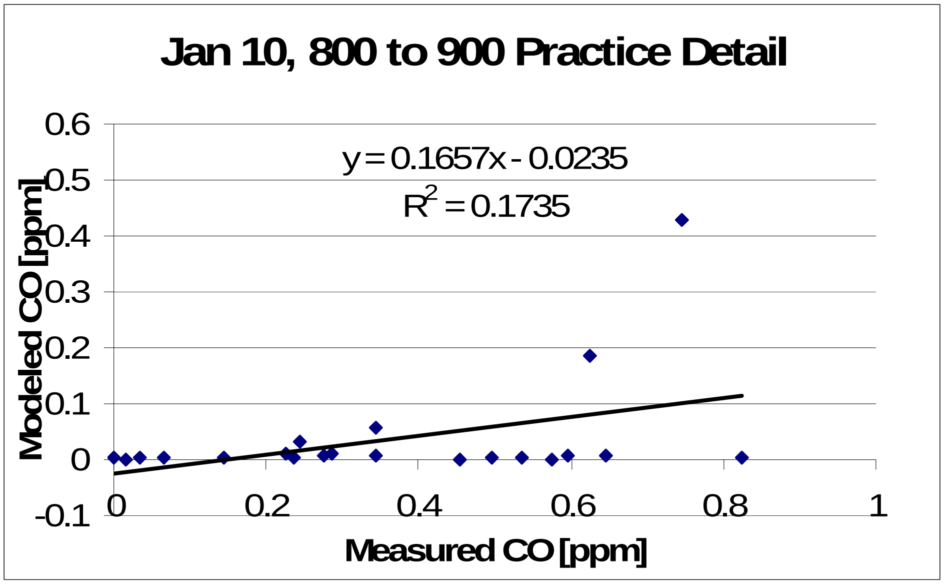

Figure 147 Jan 10, 8 to 9 Practice Detail Modeling Linear Regression

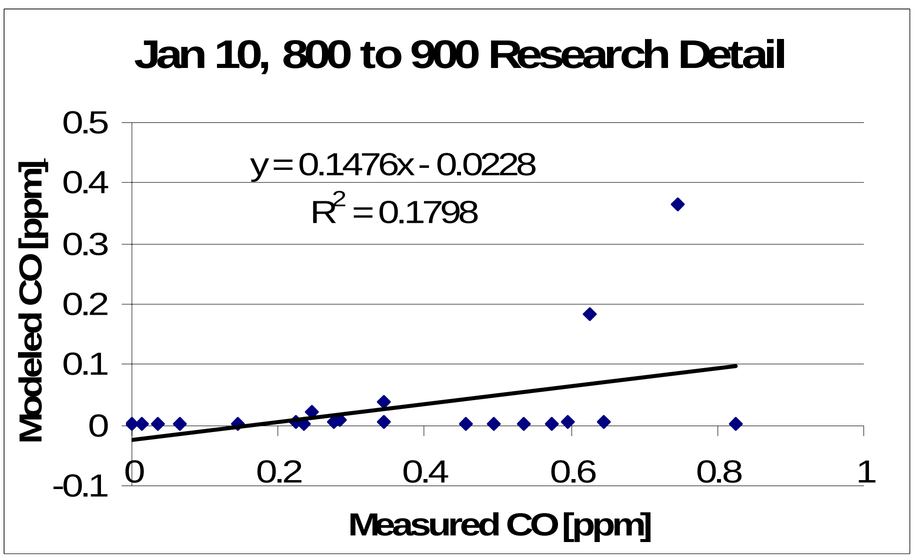

Figure 148   Jan 10, 8 to 9 Research Detail Modeling Linear Regression

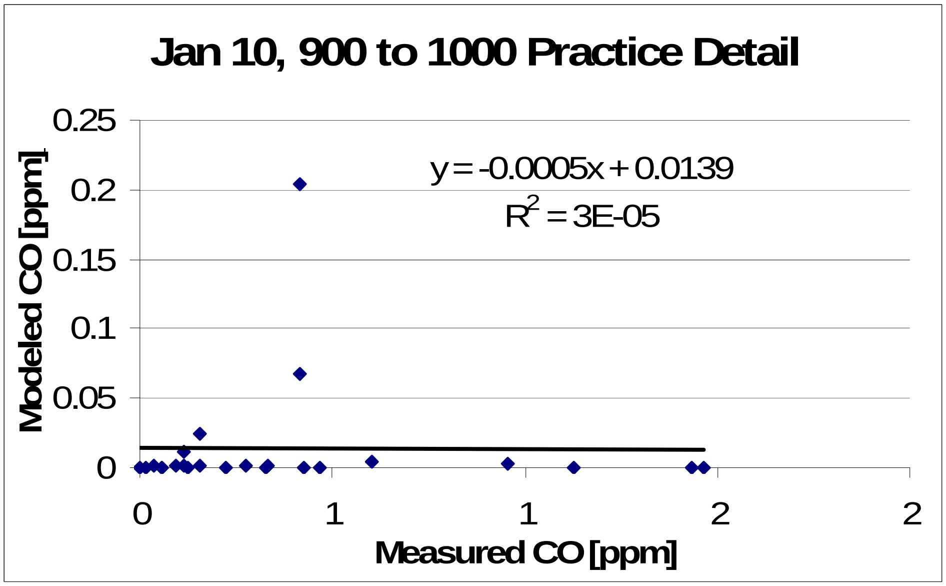

Figure 149 Jan 10, 9 to 10 Practice Detail Modeling Linear Regression

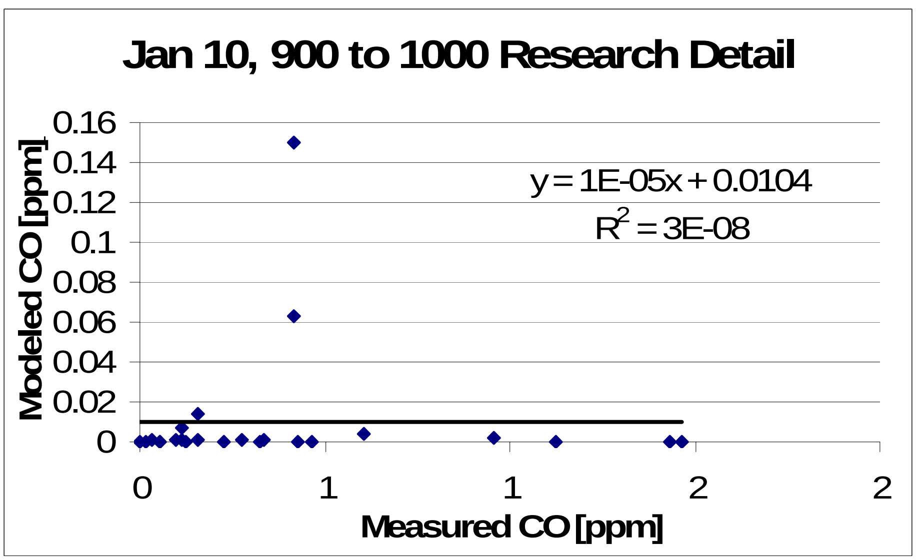

Figure 150 Jan 10, 9 to 10 Research Detail Modeling Linear Regression

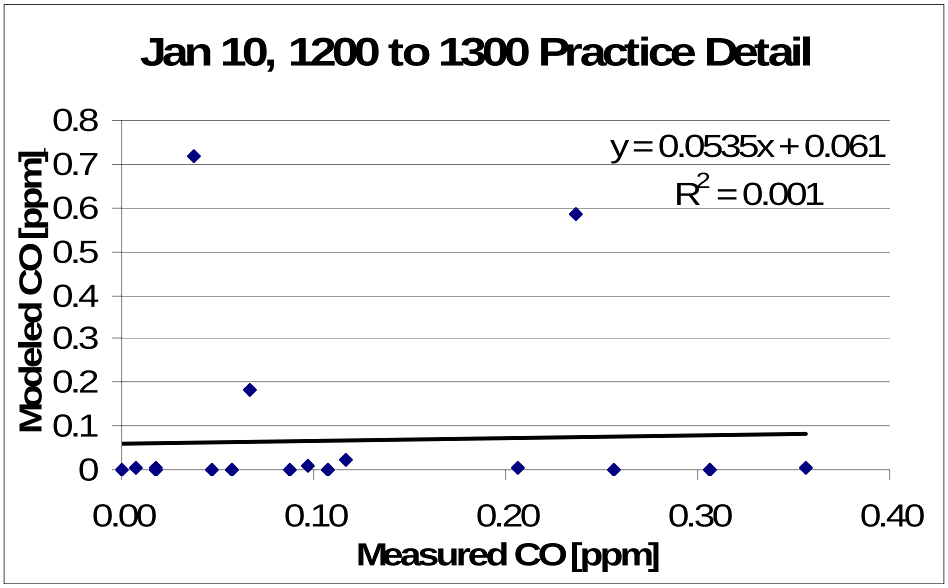

Figure 151 Jan 10, 12 to 1 Practice Detail Modeling Linear Regression

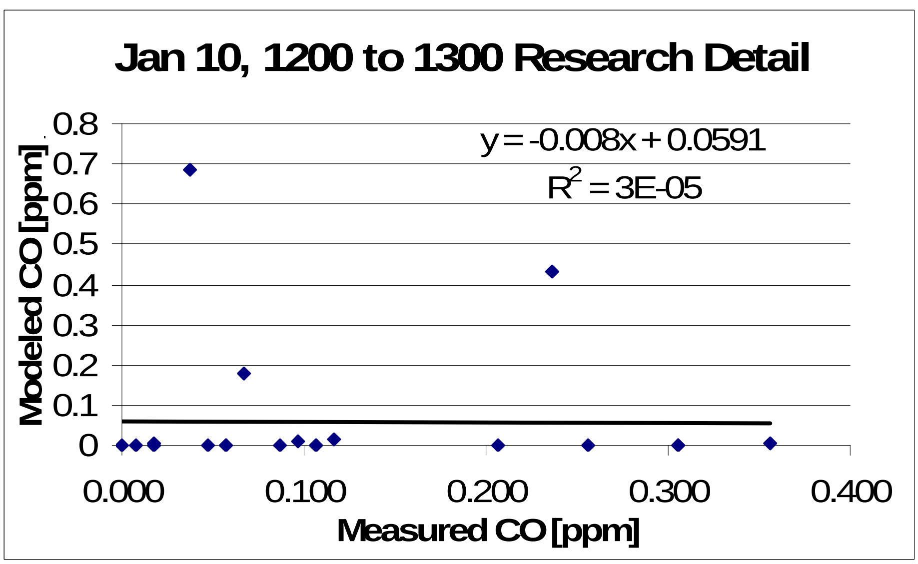

Figure 152 Jan 10, 12 to 1 Research Detail Modeling Linear Regression

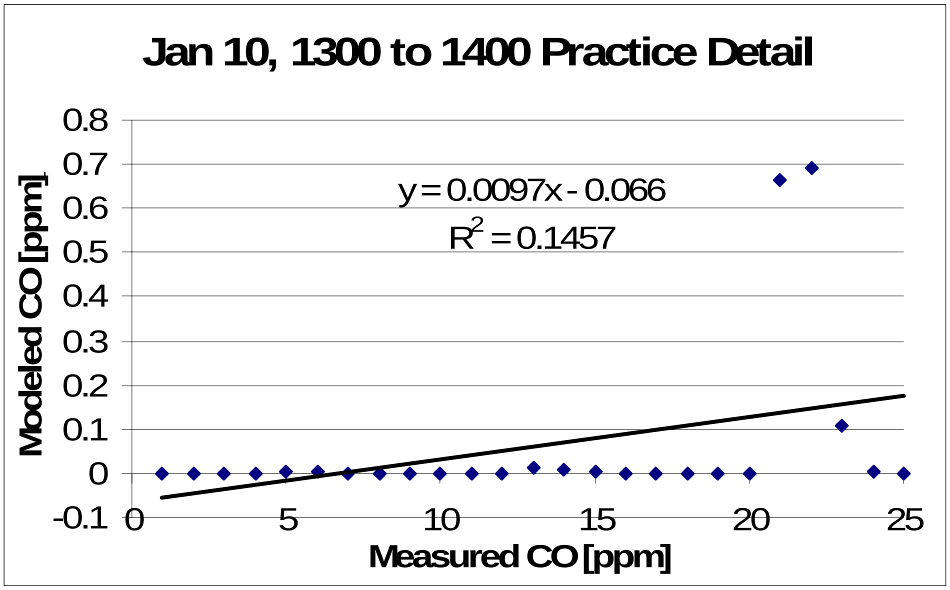

Figure 153 Jan 10, 1 to 2 Practice Detail Modeling Linear Regression

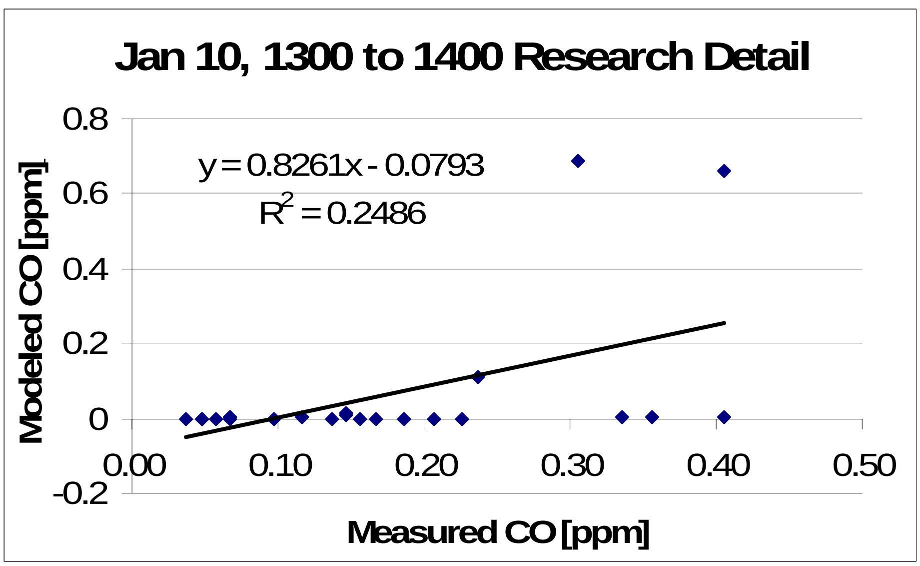

Figure 154 Jan 10, 1 to 2 Research Detail Modeling Linear Regression

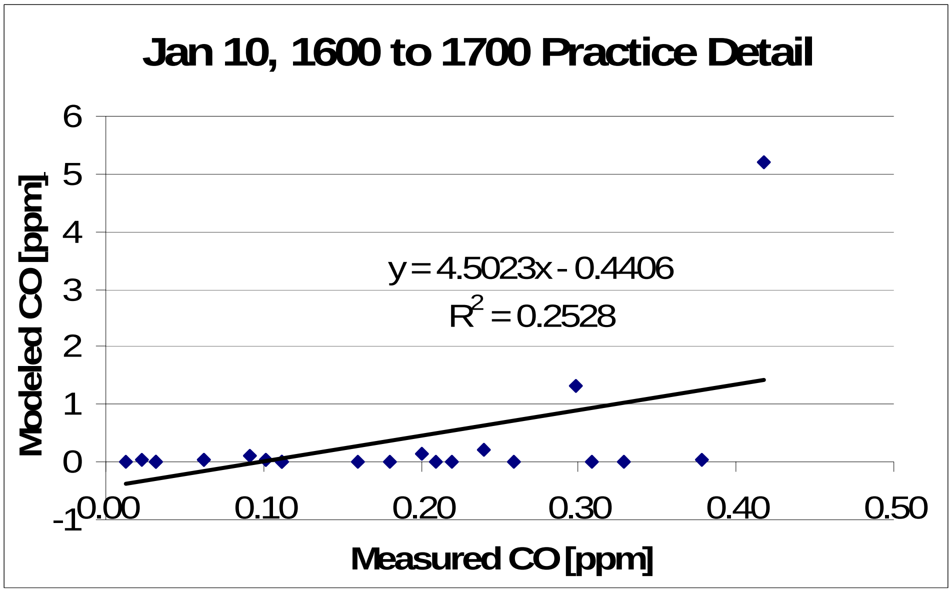

Figure 155 Jan 10, 4 to 5 Practice Detail Modeling Linear Regression

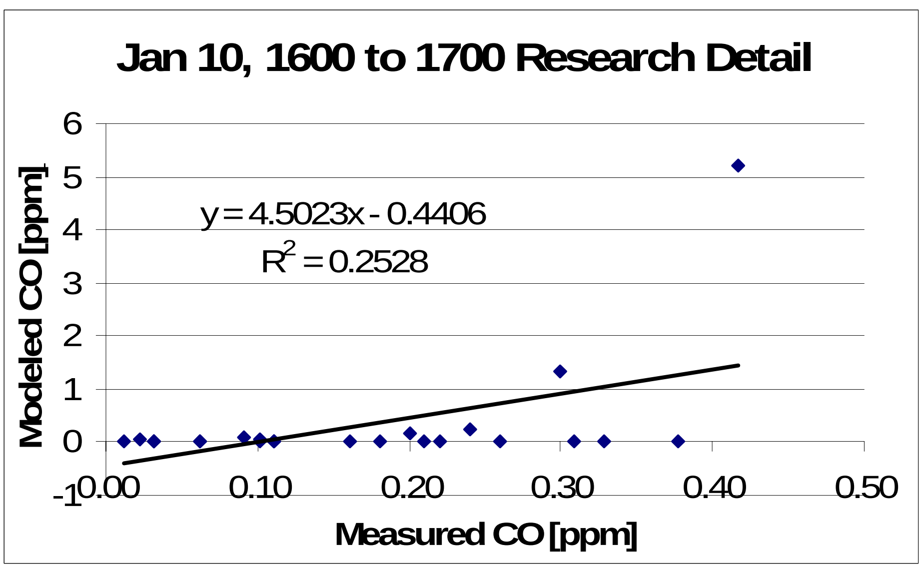

Figure 156 Jan 10, 4 to 5 Research Detail Modeling Linear Regression

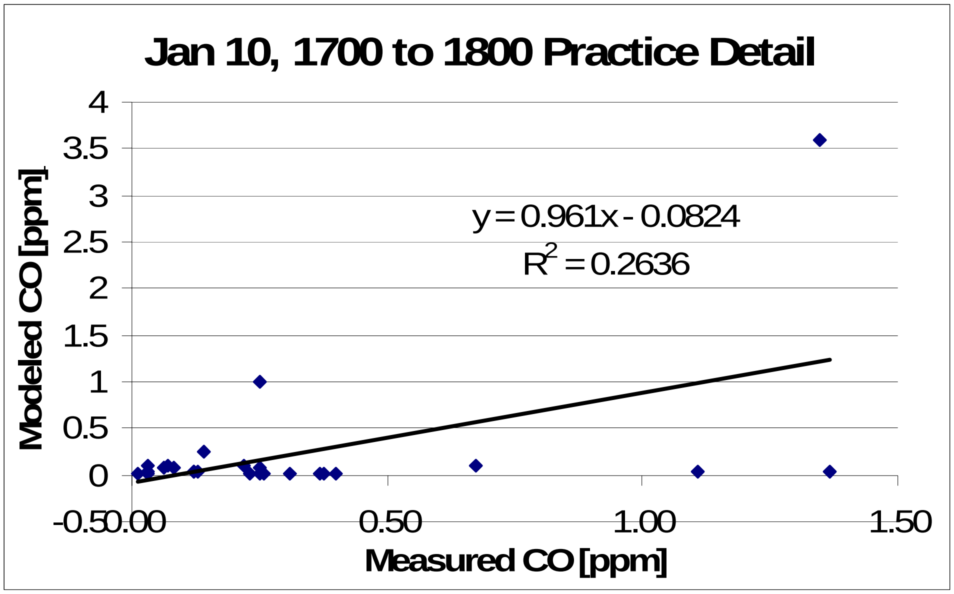

Figure 157 Jan 10, 5 to 6 Practice Detail Modeling Linear Regression

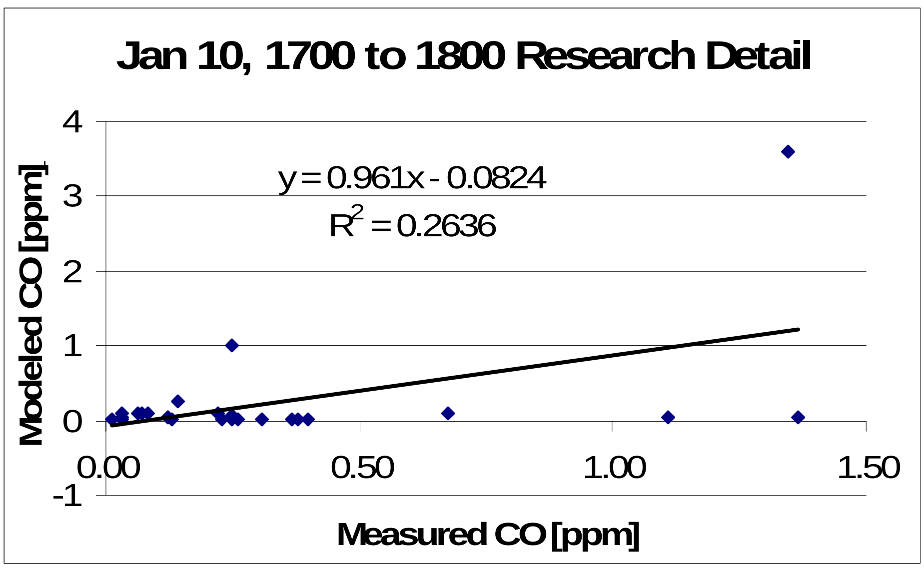

Figure 158 Jan 10, 5 to 6 Research Detail Modeling Linear Regression

APPENDIX C – STATISTICAL TABLES

Table 11 January 8th t-test Results

	January 8th p-values calculated (t-test)	
	Measured vs. Practice	Measured vs. Research
800 - 900	0.395488148	0.447193373
0901 - 1001	0.000461752	0.000461752
1200 - 1300	0.012759403	0.012759403
1301 - 1401	0.054085167	0.054085167
1600 - 1700	0.019115468	0.019115468
1701 - 1800	0.133830231	0.141653253

Table 12 January 9th t-test Results

	January 9th p-values calculated (t-test)	
	Measured vs. Practice	Measured vs. Research
800 - 900	0.987411987	2.12009E-05
0901 - 1001	2.24663E-07	2.24663E-07
1200 - 1300	0.007724845	0.004127273
1301 - 1401	0.33472849	0.250300409
1600 - 1700	0.488456054	0.488456054
1701 - 1800	0.378241445	0.526831629

Table 13 January 10th t-test Results

	January 10th p-values calculated (t-test)	
	Measured vs. Practice	Measured vs. Research
800 - 900	1.94065E-06	1.49966E-06
0901 - 1001	0.000305423	0.000270691
1200 - 1300	0.359662049	0.237762601
1301 - 1401	0.005210318	0.003844585
1600 - 1700	0.519490282	0.551068749
1701 - 1800	0.452261461	0.436192417

Table 14 January 8th Pearson Correlation Coefficients

	Pearson Correlation	
	Measured vs. Practice	Measured vs. Research
800 - 900	-0.074	-0.070
0901 - 1001	-	-
**1200 - 1300	-	-
**1301 - 1401	-	-
**1600 - 1700	-	-
1701 - 1800	0.070	0.078

** not possible when model predicts all 0s

Table 15 January 9th Pearson Correlation Coefficients

	Pearson Correlation	
	Measured vs. Practice	Measured vs. Research
800 - 900	0.340	0.321
**0901 - 1001	-	-
1200 - 1300	0.048	0.067
1301 - 1401	-0.096	-0.097
1600 - 1700	0.721	0.721
1701 - 1800	0.640	0.655

** not possible when model predicts all zeros

Table 16 January 10th Pearson Correlation Coefficients

	Pearson Correlation	
	Measured vs. Practice	Measured vs. Research
800 - 900	0.415	0.422
0901 - 1001	-0.004	0.001
1200 - 1300	0.033	-0.004
1301 - 1401	0.499	0.498
1600 - 1700	0.503	0.502
1701 - 1800	0.513	0.513

APPENDIX D – CONTRIBUTING PERSONAL

Volpe National Transportation systems Center, Measurement and Modeling Facility:

Gregg G. Fleming

B.S., Electrical Engineering, University of Lowell, MA. Mr. Fleming is the Chief of the Volpe Center's Measurement and Modeling Division. He was responsible for all aspects of the study.

Roger L. Wayson

Ph.D., Civil and Environmental Engineering, Vanderbilt University, Nashville, TN. Dr. Wayson was responsible for study design, and oversight in the field. He was also responsible for data reduction and analysis, and modeling support.

Brian Kim

Ph.D., Environmental Engineering, University of Central Florida, Orlando, FL. Mr. Kim provided field data collection, data reduction and analysis, and modeling support.

Nancy E. Garrity

M.S., Civil and Environmental Engineering, Tufts University, Medford, MA. Ms. Garrity provided field data collection, data reduction and analysis, and modeling support.

John McDonald

Ph.D., Environmental Engineering, University of Central Florida, Orlando, FL. Dr. McDonald provided field data collection, and data reduction and analysis support.

Mike Lau

B.S. Computer Engineering, Boston University, Boston, MA. Mr. Lau was responsible for all aspects of equipment preparation and fielding, and assisted in field data collection and reduction.

Joe Ruggiero

M.S. Computer Science, Boston University, Boston, MA. Mr. Ruggiero provided field data collection support.

David R. Read

Computer Specialist. Mr. Read was involved with all aspects of equipment preparation and fielding.

Christopher J. Roof

B.S., Electrical Engineering and Music, Boston University, Boston, MA. Mr. Roof was responsible for the collection and processing of site survey data.

Gary Baker

B.S. Geography, University of Massachusetts, Boston, MA. Mr. Baker provided Geographic Information Systems (GIS) support as part of data reduction, analysis, and modeling.

Anjoli K. Martin

B.S., Environmental Engineering, University of Central Florida, Orlando, FL. Ms. Martin was responsible for compilation of all input sources into EDMS, as well as modeling the data and organizing the output data.

FAA:

Julie A. Draper

B.S., Applied Mathematics, James Madison University, VA. Ms. Draper was an FAA project manager on the study, overseeing all aspects of the study.

Warren Gillette

B.S., Chemistry, Frostburg State University, Frostburg, MD. Mr. Gillette assisted with clearances, project staffing, and collected air traffic data.

Aimee Fisher

B.A., English, University of Arkansas, Fayetteville, AR. Ms. Fisher provided GSE data collection support.

Carl Ma

B.S., University of Wisconsin, Madison, WI. Mr. Ma provided road traffic data collection support.

Ed McQueen

B.S., Civil Engineering, Howard University, Washington, DC. Mr. McQueen provided air traffic data collection support.

Angel Morales

B.S., Electrical Engineering, RUM, Mayaguez, PR. Mr. Morales provided field data collection support.

Dulles International Airport:

James C. Rushing

Rick Rodine

Jon Byroade

CSSI:

Theodore Thrasher

B.S., Aviation, The Ohio State University College of Engineering, Columbus, OH. Mr. Thrasher managed the CSSI, Inc. resources for the study and provided aircraft-related data collection support.

Clifford Hall

B.S., Mathematics, B.A. Physics, Drake University, Des Moines, IA. Mr. Hall provided aircraft-related data collection support.

Tamara Breunig

B.S., Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA. Ms. Breunig provided vehicular and aircraft-related data collection support.

Yodit Getachew

B.S., Aerospace and Computer Science, Embry-Riddle Aeronautical University, Daytona Beach, FL. Ms. Getachew provided vehicular data collection support.

N. Mariano Pernigotti

M.S., Information Management, Marymount University, Arlington, VA. B.S., Aeronautical Science, Embry-Riddle Aeronautical University, Daytona Beach, FL. Mr. Pernigotti provided vehicular data collection support.

Robert Petty

B.A., Management, National-Louis University. Mr. Petty provided vehicular data collection support.

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